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PREFACE

The pecan is a uniquely American crop that has been transformed from a wild component of the riverbottom ecosystem to the economically most significant native cultivated North American horticultural crop. Its economic success is largely due to the research accomplishments of the many dozens of pecan scientists that have studied pecan and its interaction with environmental factors. Advances in the development of propagation methods, cultivation techniques, pest management strategies, nutrition, irrigation technology, harvesting, postharvest handling, and genetically improved cultivars have served to propel and expand the industry. These advances have had the positive benefit of greatly increasing the national production of quality nuts, however they have had the side-effect of greatly increasing production costs. During the last decade or two, the impact of inflationary forces on the costs of orchard inputs, and a concurrent failure by the industry to increase demand and to adequately regulate nut quality, has resulted in pecan producers experiencing a severe 'cost-price' squeeze that currently threatens the economic integrity of many growers. This new stress is but the latest of a string of stresses that have acted upon the pecan industry since its inception and have served to both direct the evolution of the industry and to determine its nature. Within each challenge, has existed an opportunity for those individuals possessing sufficient insight and/or creativity. While the industry will obviously survive this new stress, its future characteristics will largely depend upon the ability of pecan scientists (and the industry itself) to successfully address ways of reducing production costs and to increasing demand. We researchers can impact both of these areas of concern.

It was felt by the National Pecan Research and Extension Workers group that pecan husbandry had reached the point where scientists could not effectively resolve production, pest or marking related problems without possessing a fairly good understanding of nearly all aspects of pecan husbandry. Husbandry is now especially complex, possessing many interrelationships between production, pest, quality, marketing, etc. For example, frequently that which is recommended to resolve a production problem acts to aggravate a pest problem, or vice versa. Scientists must therefore be sensitive to, and have a rudimentary understanding of, nontarget problem areas if they are likely to make significant contributions.

Groups of pecan scientists have occasionally met throughout the last few decades in response to stresses limiting the growth of the industry, however this workshop appears to be the first such meeting that is both national in scope and encompasses all scientific disciplines that are directly related to the industry.

The workshop objectives were to a) clarify the primary factors contributing to the cost-price squeeze, b) educate scientists as to the nature of the problem and how it interacts with other problems and disciplines, c) encourage cooperative efforts to address these problems, d) to gain insight into new areas of research, e) to provide new ideas and concepts, and f) to encourage greater communication among researchers.

It is this participant's belief that these objectives were generally satisfied and that this workshop will have a significant and long-term positive impact on not only the evolutionary characteristics of the pecan industry but also further domestication of the species. The decision by the NPREW group to make this a reoccurring workshop focusing on different themes at different locations provides substantial evidence for the degree of success enjoyed by this First National Pecan Workshop.

As the designated convener of this workshop, I would like to thank all those in attendance for their contributions (both direct and indirect), the program committee (Jerry Payne, Glen Taylor, L.J. Grauke, James Dutcher and Bruce Wood) for their successful effort in assembling a comprehensive and pertinent program. Sincere thanks is also extended to all those who participated on the program and to those who prepared their presentations for publications in this proceedings.

Bruce W. Wood
Byron, GA.

CONTENTS

THINK TANK SESSION

PROTECTION-ARTHROPODS

PROTECTION-DISEASES

PRODUCTION

QUALITY, ECONOMICS AND MARKETING

PECAN GENETICS AND IMPROVEMENT

Tommy E. Thompson[1]

Perhaps nothing is more important to the future of this crop than improvement through breeding. The importance of this subject demands adequate consideration of breeding strategies. We must be critical and shrewd in our breeding philosophy to effectively use the limited resources in our breeding program. I believe candid and open discussion of this matter will contribute to future breeding success.

Throughout this paper, comparisons between Persian (English) walnut and pecan are made. Walnut is the major nut crop most closely related to pecan, so it is useful for comparison purposes. We must remember, however, that the two crops are dissimilar in important respects. Understanding these differences is imperative when we begin to base pecan yield improvement expectations upon yieldability of walnut.

Contrary to the conclusions of Wolstenholme and Malstrom (1980), pecan and walnut do not have a similar breeding history up to about 1950. Man has improved walnut by selection for thousands of years (Jaynes 1979). Pecan has been artificially selected for only about 100 years.

Trait Heritability

The heritability of yield and quality characteristics of pecan have been determined to a limited extent. We (Thompson and Baker 1988) found low heritability for nut weight (.35), kernel weight (.38), and percent kernel (.32). These low levels resulted, to some extent, from failure to control environmental variability. This knowledge will allow some accuracy in predicting progeny distributions for different traits. I do not believe this has greatly limited pecan improvement through breeding in the past. Breeders of all crops tend to know general levels of heritability of different traits before these are scientifically determined and published. Such knowledge is gained through experience and observation. It is much of the "art" of plant breeding. For example, Russian breeders doubled the seed oil content of sunflower from about 28% to nearly 60% from 1920 to 1975. This was all accomplished before the formal determination of heritability estimates for this trait by Fick (1975). Such knowledge, however, should be useful in refining breeding strategies for pecan in the future.

Yieldability

Pecan has not experienced rapid yield improvement in the recent past for many reasons. Perhaps the dominant reason is the late seasonal period of nut-filling. This basic difference between walnut and pecan was obvious to me early in my comparing walnut and pecan at Brownwood, TX. On June 21 (the longest day of the year), the fresh weight of Persian walnuts at Brownwood was 100 times that of the small developing pecans. Walnut seems to fill at an ideal time to produce high yields and to avoid alternate bearing. The shell is full size by mid- June and embryo growth can be detected in late June. The walnut is out of the water stage by the end of July. Pecan, by comparison, reaches full nut size about the first of September. The water stage is still common in many cultivars during the last part of August. Essentially, pecans fill late in the season when the days are shorter, after the leaves have often been damaged by insects and disease, when the trees require photosynthate to replenish root reserves for winter, and perhaps when the soil in some parts of the pecan belt is drier than at any other part of the season.

The advantages of an earlier and longer nut-filling period in pecan are many: (1) alternate bearing cycles should be diminished since carbohydrate reserves of roots would be more adequately replenished in the fall. The trees should enter the dormant season with greater root reserves and begin growth more vigorously the following spring. They should also have nutritional conditions more favorable to high production in the spring (Smith and Waugh 1938);

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(2) The crop would be harvested earlier, giving a marketing advantage; (3) Weather for harvest should be better; (4) Leaves would remain on trees during shaking, eliminating this source of trash; (5) There might be a dwarfing effect on the spring growth of pecan due to the photosynthate being used by the tree to produce nuts instead of more unneeded wood. Perhaps pecan trees would be dwarfed to some extent by this effect as perhaps Persian walnut is. This seems desirable since young developing orchards would initially grow well and vigorously before they produce nuts. After they started bearing, and when limited growth would be desirable, it would be self-imposed by the bearing habit of the tree.

In addition, earlier nut-maturing cultivars could be grown further north; and since harvest is earlier, winter cover crops could be established earlier.

There may be one disadvantage here. Oilseed crops (pecan could be considered one) tend to produce seed higher in oil and higher in unsaturated fatty acids when produced under cooler conditions (Canvin 1965). Filling pecans in July and August would subject them to higher temperatures than the present filling time in September. In California, walnut may largely escape this effect since the temperatures, especially night temperatures, are much lower (Table 1). Relative humidity is also lower, allowing more effective daytime leaf cooling by transpiration (Table 2).

Time of nut-filling appears to be largely a quantitative genetic trait. However, segregates outside parental ranges (transgressive segregates) have been produced in the Brownwood breeding program. For example, 'Osage' is one of the earliest filling clones we have. Both of its parents, 'Major' and 'Evers', fill later.

Hickory immediately comes to mind as a genetic source of earliness. It is much like the Persian walnut in this regard. Introgression of this germplasm into pecan would require many sexual cycles. One could not be optimistic in such a breeding program unless juvenility could be overcome to greatly shorten the generation time.

Lengthening the nut-filling time is another way to increase yields in many crops. The length of this stage is generally known for pecan (the last week of August through the first week of October), and it appears that a much longer nut-filling period would be desirable. The nut-filling time in walnut appears to be longer than in pecan.

Lateral Branching

Lateral branching and fruiting are the traits often discussed when comparing walnut and pecan. Many see a simple relationship between this character and yield and suggest that walnut breeders have doubled yield with it and pecan workers have ignored it. In walnut, lateral branching allows the number of pistillate flowers to be increased dramatically, mainly in young trees. In some very high-yielding cultivars (e.g., 'Chico'), the large number of nuts per tree seems to decrease nut size slightly.

In walnut, lateral branching is strongly correlated with precocity. This characteristic is very important since orchards of lateral branching cultivars come into production early. In pecan, precocity and prolificacy as a mature tree are probably strongly related. Increased branching and a high proportion of fruiting branches are needed. 'Wichita' is a good example of a low level of this desirable trait in pecan.

Cluster Size

Cluster size is much smaller and more uniform in walnut (usually 2 compared to 1-7 for pecan). California walnut breeders believe this small cluster on almost every growing point is desirable to better distribute the photosynthate (source-sink relationship) demands of the developing nuts. We currently can only presume that pursuing breeding objectives to produce more and smaller clusters in pecan would be desirable.

Scab Resistance

Scab screening is and should remain a major part of the pecan germplasm improvement program. The contention that there is a negative correlation between yield and resistance to this disease is unproven. I have determined correlation coefficients of yield and scab ratings for cultivars in three yield tests. The yield tests were conducted at Melrose, Louisiana (27 cultivars), and Albany, Georgia (24 cultivars). These two characteristics were unrelated in each test. It is true that some high-yielding cultivars are scab susceptible ('Wichita', 'Cherokee'). Many low-yielding cultivars are also scab susceptible.

Since scab is one of the most important disease on pecan and annually costs producers millions of dollars, initial seedling screening for resistance (which is done relatively easy) is being conducted on a portion of the breeding material.

We need to know more about pathogenic races and resistant gene interactions to make intelligent choices of which resistance genes to use in breeding. Glen KenKnight tested different scab sources (collected from different cultivars) on a large number of standard cultivars to define the situation of pathogenic races. This is a beginning of the obvious needs in basic scab research. Also, screening techniques for specific resistance genes should be developed based on the above knowledge base.

Other diseases and pests should also be controlled through breeding for resistance. Resistance to at least some of these diseases and pests (e.g., aphids and Phylloxera) is probably specific and due to qualitative genes in the host. Basic genetic studies of these resistance mechanisms, along with concurrent identification of resistant germplasms, would be a good investment in the long range improvement of this crop.

SUMMARY

Pecan does not yield as much as Persian walnut. This is probably due to its late nut development period and a much shorter nut development period.

Breeding earlier maturing pecan cultivars that have longer nut-filling periods should have the following advantages:

1. Irregular bearing should diminish since carbohydrate reserves of roots would be more adequately replenished in the fall.
2. The earlier harvest would be a marketing advantage.
3. Weather for harvest should be better.
4. Leaves would remain on trees during harvest, eliminating a source of trash.
5. There possibly would be a dwarfing effect upon mature tree growth due to more photosynthate being used to produce nuts instead of unneeded wood.
6. Improved pecan cultivars could be grown further north.
7. Winter cover crops could be established earlier.

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Table 1. Average monthly temperatures for Visalia, CA and Brownwood, TX.

Month	Visalia	Brownwood
May	69.2	72.6
June	75.8	80.7
July	82.1	84.2
August	79.9	84.1
September	75.2	77.0
October	65.4	67.4

Table 2. Comparison of walnut growing area in California (Visalia) and one pecan growing area in Texas (Brownwood).

	Visalia
Relative humidity (Summer)	Lower
Temperatures (Summer)	Lower
Growing Season	20-70 days longer
Spring leafing date	1 month earlier
Fall leaf shedding	1 month later
Soils	Better

PECAN ARTHROPOD MANAGEMENT

Marvin K. Harris[1]

ABSTRACT

Masting, genetic diversity, and natural enemies are primary components in the natural defense arsenal of pecan to nut and foliage pests. The practice of chemical agriculture has replaced these defenses especially in vegetatively propagated orchards that appear destined to constitute the entire industry. The demise of chemical agriculture due primarily to biological (resistance), but also to economics, political, and social forces jeopardizes the industry and demands that alternatives consistent with an orchard life of 100+ years be seriously considered. Pecan arthropod management affects and is affected by other management practices. Progress in adapting pecan production methods to meet society's needs will benefit from a more integrated holistic approach compared to the compartmentalized, reactive programs that have brought us to the present.

INTRODUCTION

Pecan arthropod management practices today are a legacy inherited from our predecessors stretching back in time more than 4,000 years to "when the Sumerians used sulfur compounds to control insects and mites" (Bottrell 1979). Pest control by manipulation of natural enemies, application of chemicals, and the use of physical and cultural methods all originated before the Christian era. Human ingenuity and time have combined to provide us the tools we presently use to minimize the adverse effects pest arthropods can have on food and fiber production and storage. Despite these massive, extensive and creative efforts, we are still routinely plagued by pest arthropods. Events within the past decade involving Medfly, *Ceratitus capitata*; Africanized honey bee (so-called killer bees), *Apis mellifera*; and ticks that vector Lyme disease illustrate our continuing vulnerability to pest arthropods.

A prime example in the pecan industry occurred in 1985 when the Federated Pecan Growers Association declared pecan aphids to be the number one pest and noted that the problem was so severe that the entire industry could fail if the aphids could not be dealt with effectively. The primary point here is that pest arthropods consistently pose difficult challenges to human progress throughout our culture and, pecan production, despite technological advances, continues to suffer its share of problems from pest arthropods as well.

The reasons for these continuing difficulties are many, but two factors address the core of the problem. The majority of arthropod pest problems are both complex and dynamic. Complexity means that solutions are hard to come by and a dynamic quality implies today's solution may not solve tomorrows problem. In fact, today's solution may actually cause tomorrow's problem. This is especially true where living organisms are involved. Those capable of surviving changes in their environment confer these capabilities to their offspring thereby allowing just a few survivors of, say, pesticide treatments, to give rise to an entire, epidemic level, population of survivors.

Another kind of complexity is introduced by increased involvement and concern by the public, expressed both through laws and supermarket purchases, in how pest and other problems are solved. The alar controversy is one example and the removal of phosalone from pecan is another. Chemical agriculture will be less dependable in the future for this reason as well.

The resolution of pecan arthropod problems in production agriculture can only be accomplished by developing an understanding of this complex system and by anticipating how that system will be affected by specific solutions. The approach taken by the Pecan Insect Laboratory at Texas A&M University is to compare and contrast the survival mechanisms inherent in the unmanaged pecan with the production requirements placed on the commercial pecan (Harris 1980). This allows us to examine how pecan interacts and survives with arthropods in natural situations and then to focus on how and why particular arthropods achieve pest status in commercial situations. This broad perspective provided useful insights that resulted in effective management approaches in this complex and dynamic system. Although much progress has been made, primarily through the Southern Regional Project on Pecan Arthropods, in which my lab participates, we have only begun to understand the complex and dynamic features of this

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agroecosystem, and to convert that knowledge to management approaches that result in greater quantities of high quality reasonably priced pecans available to consumers everywhere throughout the year and provide a fair return to the producers. The purpose of this paper is to take a broad view of pecan arthropod management in the context of pecan production and to attempt to anticipate problems and consider options from a wider perspective than is usually taken.

PECAN DEFENSES AGAINST THE PECAN PEST COMPLEX

There are five defense mechanisms whereby a plant species can survive phytophagy and these can be expressed from the subcellular to the individual to the population level of organization. These mechanisms are escape in space, escape in time, confrontation, accommodation, and biological associations (Harris 1980). These defenses allow transmission of superior phenotypes from one generation to the next by natural selection (Grant 1977).

Pecan utilizes all these mechanisms in the natural environment and what little is known has been reviewed elsewhere (Harris 1980, 1988). A principal feature for pecan is masting (synchronous nut production over wide areas at irregular intervals) to escape primary nut feeders by periodic satiation and starvation. Confrontation of pests like pecan phylloxera and pecan scab is a population phenomenon where individual trees may succumb but the diverse population is protected from an epidemic (Browning 1980; Harris 1980). Accommodation of foliage feeders by universal susceptibility to periodic defoliators like walnut caterpillar and to some extent, aphids, preserves the masting cycle for the pecan and natural enemies keep the pest in check most of the time (Harris 1980). The selection and vegetative propagation of annually productive pecan in large genetically uniform monocultures drastically reduces mechanisms for escape in space and time and eliminates confrontational mechanisms based on population diversity. Protection with broad spectrum pesticides eliminates many favorable biological associations and supplemental fertilization and irrigation improves nutritive quality and extends windows of susceptibility to pests that could otherwise be escaped, confronted or accommodated. Pecan arthropod management programs have largely developed in a reactive capacity without providing input on long range development plans for the industry. Given that a failure to solve pest problems can eliminate a crop from a wide production area, i.e., sugar beets, sugar cane, cotton and sunflower have all been driven from production from some areas due to pests, a production system that does not capitalize on all natural defense mechanisms compatible with commercial production may increasingly risk failure. Greater attention needs to be paid to the limited information available in this area and further work should be supported to identify and capitalize upon risks and rewards using this approach.

PECAN HISTORY

Carya illinoensis (Wang) K. Koch is native to North America from the Mississippi River Valley to West Texas and into Mexico (Little 1971). Brison (1974) notes the pecan is the most important horticultural crop native to the United States. The American Indian relied on pecan nuts nature provided for food; but, serious domestication of the tree really began when early settlers thinned wild mixed species stands of trees to leave some pecan and create a pasture understory for cattle (Table 1). The earliest orchards were established by seed followed by development of vegetative reproduction technology in the middle of the last century allowing the "best" varieties to be propagated wherever the trees would grow. This technology and an entrepreneurial spirit resulted in an extensive expansion of the pecan industry into the southeastern U.S. in the early 1900's and to the west of the Pecos in the 1930's and continuing to the present. Conversion from thinned stands of wild pecan to vegetatively propagated orchards in the native range was very slow because nuts produced by wild trees were and are competitive with those from improved varieties.

Native pecan producers are reluctant to remove producing trees, even those a century old or more, and plant an orchard in their place because of: 1) The initial expense; 2) the time required to recoup that investment from new production; 3) the change in life-style from a cattle/pecan mixed agriculture system to pecan monoculture; and 4) other uncertainties in such a long-lived crop like fluctuating prices and revisions of tax law. Consequently, about 50% of the 300 million lbs. of pecan nuts produced annually in the U.S. come from trees nature planted or grown from seedlings, with the remainder produced primarily from a dozen or so of the 1,000 plus vegetatively propagated "cultivars" noted by Thompson and Young (1985).

These origins provide a diversity of production situations on a large scale that has no parallel in any other crop grown in the U.S. and research opportunities that allows investigation of pecan arthropods from their natural state to intensively managed production agriculture conditions with all manner of intermediate situations available for study as well. Investigation of the complex and dynamic nature of the arthropod/pecan interaction and its impact on production agriculture benefits from this diversity because field situations can be found to actually test hypotheses in pecan whereas only speculation and computer simulation would be possible in most other crops.

The diversity of pecans available today is, however, much less than that at the turn of the century. Native pecans and seedling orchards are not to any appreciable extent being replaced as they die. Slowly but surely the base for commercial production is being shouldered by the "best" of the vegetatively propagated cultivars and this uniformity provides greater opportunities for pests previously kept off-balance in environments where every tree was genetically distinct. The effects of this increasing uniformity were recognized 60 years or more ago as pecan scab became more severe and 20 years or so ago as pecan twig phylloxera was observed to preferentially attack specific cultivars. Resistance "breaks down" is the common observation, but in reality the virulence of the pest "catches up" with the now genetically frozen pecan planted in monoculture. Wheat and other annual crop farmers can deal with this kind of problem by switching varieties (Harris 1980). That solution is of limited value with current pecan technology, and increased narrowing of the germplasm means similar problems will occur in the future.

The trend towards having more and more of our production dependant upon a narrower and narrower genetic base is a potential time bomb in a production system with a useful life of 100-200 years. A narrowed genetic base unquestionably reduces the ability of the pecan to defend itself against arthropod and pathogen attack and artificial defenses using chemicals, sanitation, etc., are needed to maintain productivity (Harris 1980, 1983, 1988). If diversity can save one treatment at $60/hectare each year and those profits were invested at 6% annually, the compounded return would be $338 thousand after 100 years and $114 million after 200 years. The analogy is admittedly unrealistic because of the unknowns of inflation, taxes, acts of God, war, etc., but is this less visionary than planting a new orchard to the "best" cultivar and one or two pollinators and expecting current budget figures to apply over the same time frame? History shows the narrower genetic base becomes increasingly plagued with pest problems requiring more and more overt management to maintain the same level of production so that today's advantages are often rapidly lost. The inability to rapidly and economically switch cultivars should cause us to ask how much diversity is needed to prevent or delay the need for overt management?

Varietal selection and breeding programs serve as the predominant source of new cultivars. These efforts emphasized precocity, productivity, and marketability of specific selections based on limited evaluations over short time spans compared to the century plus life of orchards planted to them. This is analogous to a football team composed exclusively of wide receivers that can surprise the opposition for a while but ultimately suffers from a lack of balance. Rectifying this weakness will require modifying our selection requirements from the individual archetype to the population archetype that allows improvement while maintaining diversity.

PECAN MANAGEMENT

Current management practices vary from treating the pecan as a gift of nature and harvesting the trees when they produce a crop to state-of-the-art systems of high density, carefully selected and pruned cultivars that are irrigated, fertilized and protected with the latest pesticides, and mechanically harvested, shelled and refrigerated in storage until being sold. The gift of nature grower harvests a crop every 2-5 years while the intensive manager expects a crop every year. No single system of arthropod management is compatible with this diversity of production situations. Careful examination of each production situation is needed and an arthropod management plan should be developed that is consistent with the overall production program (Harris 1983, 1985).

Earlier I noted the diversity of geographic areas from the arid climate and basic soils of the west to the humid climate and acid soils of the southeast where pecans are grown. These factors too can affect the options available in pecan arthropod management, particularly in regard to pesticide application using a spray machine, typically an air blast sprayer. Their primary uses are for application of zinc for prevention of rosette, fungicides for disease management, and acaricides and insecticides for arthropod

management; and, tank mixes of all three amendments can be used simultaneously to "solve" rosette, disease and arthropod problems in a single application reducing wear and tear costs on equipment and a labor and water savings of up to 66% compared to separate applications. This makes excellent economic sense when all applications are really needed but can result in unnecessary costs or even disasters when one or more of the treatments are not needed. Tank mixing unneeded insecticides or miticides with needed zinc or disease treatments is the greatest single threat to a sound arthropod management program faced by the pecan industry.

PECAN ARTHROPOD MANAGEMENT

The central consideration to a sound pecan arthropod management program is to only **undertake a management action if one or more target pests are present in sufficient numbers to seriously threaten to cause economic damage and the action taken will significantly reduce or remove that threat.** Following this guideline requires an ability: 1) To identify the pests; 2) to assess population levels; 3) to relate pest density to economic damage; and 4) to be able to take effective management action. Most arthropod research and extension efforts are directly related to these four aspects of pest management.

Figure 1 shows how the major pests in the pecan arthropod complex relates to rosette, pecan scab and other diseases. This overview illustrates that pest problems responsive to management occur from before budbreak until leaf drop, a period of about 250 days. Fortunately, the problems at a particular location can usually be reduced to a subset of the general profile in Figure 1 for many reasons. Pests differ in their distribution and intensity from location to location due to geographical barriers and climate. For example, pecan weevils do not occur west of the native range, or in Mexico, or in localized regions from Texas to Georgia, and thus pose no immediate threat to pecan production at these locations. Pecan scab is most intense where significant rainfall and high humidity coincide with rapidly growing pecan leaves and nuts and pathogen sporulation. Thus, pecan scab is of virtually no consequence in the arid west but increases in intensity as one moves east. Rosette is especially severe where pecans growing in basic soils cannot access Zn because it is tied up in such soils. Thus, rosette tends to be most severe in the limestone soils of the west and diminish in severity as soils to the east become more acidic; however, the practice of liming acidic soils to increase N uptake can also tie up Zn so that foliar Zn amendments are needed there for optimum production as well. In short, effective pecan arthropod management demands a thorough understanding of the overall context of pecan production at the specific location, as well as an understanding of the pecan arthropod complex. Extensive literature is available outlining these approaches and resulting programs (see Boethel and Eikenbary 1979; McVay and Ellis 1979; Peeples and Brook 1979; Harris 1983, 1985; Cooper et al. 1982, etc.).

The details of current IPM programs are a result of innumerable large and small changes that continuously occur to maintain profitability of pecan production. This evolution is so much a part of the fabric of production that one must deliberately reflect upon how and why we conduct them in their present form and to anticipate how future problems may be resolved.

The wild pecan produces large crops at irregular intervals and primarily defends itself against the key nut feeders, pecan nut casebearer and pecan weevil, by cycles of starvation and satiation (Harris et al. 1986, Harris 1988). Foliage feeding arthropods rarely remove more than 10% of the leaves during a season (Ring et al. 1985) and severe infestations appear to either be limited to outbreaks on single trees or widespread epidemics that affect all trees more or less equally (Harris 1980). *Phylloxera devastatrix* is an example of the former and *Datana integerrima* the latter. Note that neither type of severe foliar infestation interferes with cycles of irregular bearing in wild trees. *D. integerrima* delays the bearing year and *P. devastatrix* has virtually no effect since few trees are affected. Apparently, severe pathogen infestations are also primarily limited to single wild trees with similar effect.

The rapid adoption of vegetative reproduction a century ago has resulted in planted orchards where most trees are genetically identical contrasted to wild populations where every tree is genetically distinct. Pruning, fertilization, and irrigation in combination with selection of cultivars with a propensity to bear regular crops ensures nut production every year.

The pecan nut casebearer has been a key pest of pecan throughout the pecan-producing states east of the Pecos causing damage almost every year from at least the early 1900's until the advent of new chemicals and application equipment following WWII. Although it remained a key pest up to the present in most areas west of central Louisiana,

reference to damaging populations in the southeastern U.S. virtually disappears after the advent of mechanized chemical agriculture. I believe these differences came about because of the different driving forces at work in these diverse geographical and climatological areas.

Pecan nut casebearer (PNC) was the most important pecan pest in Texas in the late spring at the advent of the post WWII period and even though rosette and pecan scab were also problems, addressing them made little sense to southwestern growers routinely devastated by PNC. B. Hancock (Pecan Horticulturist, Extension, Texas A&M Univ., 1952-present, pers. comm.) recalls how programs to manage PNC were the impetus to also tank mix with zinc sulfate for rosette and later fungicides for pecan scab control in the mid 1950's beginning in the Guadalupe River Valley. Successful PNC control in the southwest became the cornerstone for all other management programs mediated by the new chemical application equipment and chemicals that made it possible.

Southeastern growers, in contrast, were plagued with pecan scab. This pernicious disease thrives best in hot, humid environments on rapidly growing tender pecan leaves from April to June and nutlets from May to August. The massive expanses of 30-50 year old vegetatively propagated pecans with often overlapping canopies and an excess of 30 inches of rainfall from April to September provided ideal epidemic conditions virtually every year that especially frustrated the more progressive growers because most practices that increased yield, like fertilization or zinc amendments, also stimulated and prolonged growth of tender tissue that would be infected with pecan scab. Nuts could only be destroyed once and pecan scab masked other mortality forces by a wide margin. The same breakthroughs in chemistry that produced post WWII insecticides for the southwest for PNC brought fungicides to the southeast for pecan scab (Table 1).

The time window of vulnerability to first summer generation PNC for a given orchard is about 3 weeks during the late April to early June period depending on the exact location of the orchard. Growers in the southwest could provide prophylactic coverage with two insecticide treatments during this period and achieve excellent PNC control. The primary extension scientists working with pecan immediately after WWII were horticulturists and recommending this schedule in the late spring in the southwest also ensured that two zinc treatments for rosette could be applied at little additional cost with a marked benefit in tree vigor.

The time window of vulnerability of pecan scab is dependent upon having a virulent pathogen, a susceptible host and a favorable environment. Southwestern growers in the native range were buffered from pecan scab by a preponderance of genetically diverse trees that prevented pathogen specialization and a more arid climate that produced fewer rains to constitute infection periods. Often, fungicides applied with PNC and zinc treatments prevented disease establishment in the early season and an unfavorable environment combined with a low inoculum provided sufficient protection for the remainder. Producers in the southeast faced a much tougher challenge from pecan scab (Cole 1941).

Vegetatively propagated trees severely limited the genetic diversity and allowed the pathogen to specialize on the limited varieties, and heavier and more frequent rainfall significantly extended the window of vulnerability. Enterprising growers began to spray fungicides every 2 to 3 weeks during April to September for scab control and also piggy-backed zinc and other pesticide treatments into this schedule when other pest problems became more evident in the absence of pecan scab (Miller et al. 1982).

Thus, the initial patterns for pecan arthropod management in the two major pecan production regions were established for the post WWII era. Results were dramatic in each region with the heaviest pesticide use occurring in the southeast where the window of vulnerability to pecan scab was so long. The ability to effectively manage PNC in the southwest and pecan scab in the southeast allowed producers to detect other problems that were not as obvious before like rosette, fertilization, and pecan weevil. Pecan weevil became a problem across the entire pecan belt because improved pecan management resulted in healthier more productive trees that produced large crops of sound pecans on a regular basis (Harris et al. 1980). This provided unlimited food for pecan weevil and insect populations soared. The initial answer to this problem was another chemical and today, 2-3 applications of carbaryl at 10-14 day intervals beginning in late August are used for control from West Texas to the Atlantic Coast wherever pecan weevil occurs.

The advent of effective chemical agriculture in pecan occurred later than in many other areas like cotton, corn, dairying and apple. This was primarily due to the lack of effective equipment to move chemicals into the tops of trees 20-30 meters above the ground. The pecan industry inherited chemicals from other agricultural sectors virtually as soon as they were developed,

but the first practical and effective machines were airblast sprayers modified from the fruit industry in the 1950's and early 1960's. This only explains in part how the pecan industry escaped the drawbacks of chemical agriculture much longer than other agricultural sectors; namely, arthropods resistant to pesticides, outbreaks of secondary pests, and pollution. The pecan industry is unique in that the first pest reported to be resistant to a pesticide was a fungal pathogen rather than an arthropod. Pecan scab resistant to benomyl was reported in 1975 in Georgia followed by hickory scorch mite to some carbamates and organophosphates in 1979 in Louisiana (see Harris 1983). Dutcher and Htay (1985) reported pecan aphid resistance to pyrethroids in 1985, many decades after reports on similar arthropods on comparable crops had manifested themselves. Interestingly, however, pyrethroid resistance appeared only a few years after this new class of chemical became available for use on pecan and this is a quite respectable interval if we were competing in a race for obtaining resistance.

Arthropod resistance to pesticides in pecan is primarily due to a drastic reduction of genetic diversity of pecan through vegetative propagation that predisposes orchards to increasing problems from pecan scab. This necessitates increased fungicide treatments at shorter intervals using machinery that provides thorough coverage of the foliage. A general intolerance of pest arthropods and a plethora of initially effective insecticides makes them appear "cheap" to add to the tank mix from a short-term perspective.

The cycle of subsistence, exploitation, crisis, disaster and integrated control Dutcher (1981) foresaw as also applying to the pecan industry culminated in 1985 when the Federated Pecan Growers declared the pecan aphids (secondary pests) the most important pest problem facing producers and said in essence that if the disaster was not resolved, the industry itself was in jeopardy. The southwest participated in this disaster as well, piggybacking insecticide on needed zinc and occasional fungicide treatments to the extent that one grower in the Mesilla Valley spent more than $500,000 in one year for aphid control without success. Whereas the disasters of a generation earlier in cotton, corn, apples, etc. (Bottrell 1979), and the formal IPM programs in pecan begun in 1977 (Harris 1985), were insufficient "teachable moments" to move from exploitation to integrated control, thereby skipping the crisis and disaster phases of the cycle, the pecan aphid complex proved to be the vehicle of change that brought many producers to IPM. Mark Twain observed that some matters defy description and must be personally experienced to be appreciated, and gave as his example "carrying a cat home by the tail". Perhaps, despite my earlier optimism (Harris 1983), a catastrophe must also precede adoption of IPM in each commodity.

The disaster phase of the cycle is not over even though much progress has been made in re-establishing reliance on natural enemies for aphid control in most situations. A major root of the problem is still the genetically frozen pecan that allows genetically flexible pests to fine tune their genetic capacities to exploit these massive expanses of fixed hosts so that management becomes increasingly difficult. Novel chemistry and improved equipment have, along with other technologies, kept pace with this evolution. The trend is toward less chemical development and continued reductions in the existing arsenal due both to resistance and for economic reasons, as the loss of phosalone exemplifies. Public concerns with pollution, worker safety and a wholesome food supply also indicate that reliance on chemical agriculture will diminish in the future.

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Table 1. An abbreviated history of pecan and factor affecting arthropod management.

Prior to 1800 - Native Americans gathered and subsisted on pecans in their season and early explorers and settlers readily adopted them to their diets.

1800 to 1900 - Settlers thinned tree stands in native range leaving pecans and grass for grazing. Seedling orchards established in the southeastern U.S., particularly near the turn of the century. Grafting technology for pecan developed but not heavily implemented until the last decade (Stuckey 1941). Rail transportation results in shipment of nuts to urban markets.

1900 to 1930 - Vegetative reproduction inundates southeastern U.S. with many selected varieties. Land development schemes sold small acreage of subdivided orchards (Littlepage 1913). Bordeaux spray 3-10 times recommended for nursery trees to prevent scab but large orchard trees considered unreachable; also plant resistant trees like Stuart, Schley and Frotscher (Waite 1914). Early harvest, sanitation, burning and Persian insect powder used for insect control (Morris 1912, Quaintance 1914).

1930 to 1940 - Shelling machinery, transportation and consolidations of orchards into economic units increase marketability of pecans. Expanded production of the most popular varieties like Stuart is met with increasing levels of pecan scab on previously resistant varieties (Stuckey 1941). Rosette linked to foliar zinc deficiency and lead arsenate and nicotine sulfate recommended for insect control (Rainey 1960). Spray machinery expensive, labor intensive and rarely employed (Milward 1940).

1940 to 1950 - Tank mixing of nicotine sulfate with needed fungicides recommended as "cheap insurance" (Moznette 1941 a and b). Contract spray services expand with truck-mounted hydraulic sprayers (Milward 1940, Anon. 1941). DDT used for pecan nut casebearer but aphids and mites appeared in epidemic numbers; toxaphene alone or mixed with nicotine sulfate controlled pecan nut casebearer without resurgence of aphids and mites (Rainey 1960).

1950 to 1960 - Airblast speed sprayers become generally available; compared to hydraulic sprayers (Brison 1960), the cheaper speed sprayers allow a single operator to spray the same number of trees with one-fourth the water and still obtain better coverage (Shelton 1960). Effective and economical rosette, arthropod and pathogen control with conventional and newer chemicals resulted. Malathion was adopted for pecan nut casebearer control (Rainey 1960). Chemical management of pecans became widespread.

1960 to 1970 - Cyprex and then Du-Ter replaced Bordeaux for pecan scab control and new carbamates, organophosphates and systemics became available for arthropod control (Denman 1965; Denman and Hancock 1965; Littrell 1983). Mechanization for pesticide application, pecan maintenance, harvesting and processing burgeoned along with the explosion of chemicals and solutions appeared faster than problems. Chemical schedules became routine and screening for efficacy dominated research efforts.

1970 to 1980 - Carbaryl became chemical standard for pecan weevil management, phosalone for other arthropods, Benlate and Du-Ter for pathogens, and NZN or zinc sulphate + uran for rosette. The first case of pesticide resistance in pecan was a pathogen, the causal agent for pecan scab, to Benlate in 1975, followed by an arthropod, hickory scorch mite, resistance to carbamates and organophosphates in 1979. Synthetic pyrethroids, a new class of chemicals for arthropod control, introduced late in the decade. Integrated Pest Management (IPM) philosophy develops and spreads across agriculture due to widespread pesticide resistance by arthropods, secondary pest outbreaks like aphids, mites and leafminers due to broad spectrum pesticides killing natural enemies and societal concerns about environmental pollution. Pecan industry as a whole was buffered from many of these problems because of the surfeit of chemicals for all pests (Dutcher and Payne 1982) and lagging problems of resistance due to remaining management diversity. However, aphids were viewed as a major problem in the El Paso Valley of Texas and increased reliance on natural control by predators and parasites resolved this problem there. Increased attention in pecan was paid to developing economic thresholds of important pests, refining understandings of basic biologies to predict and manage pests, to identify and rely on natural enemies of pests and other IPM strategies. Pecan IPM programs initiated in Alabama, Georgia, Texas and elsewhere late in the decade. Widespread expansion of new pecan plantings of a few varieties occurred in the Southwest and Mexico inside and outside the native range epitomizing the drastic narrowing of genetic diversity in the natural pecan population compared to the cultivated varieties.

1980 to 1990 - Arthropod resistance to pesticides becomes widespread and Federated Pecan Growers (Beshears 1988) declare aphids the most destructive pest in 1985, refuting the contention by Harris (1983) that the pecan industry had adopted IPM without the normal cycle of subsistence, exploitation, crisis, disaster and finally integrated control (Smith 1969, as quoted by Dutcher 1981). Modeling efforts and basic biological studies on pecan nut casebearer, pecan weevil, hickory shuckworm, pecan aphids, pecan scab and other pests began to be implemented into management programs (Harris 1983, Hudson 1983). Phosalone was withdrawn from the market in 1989 due to the producing companies unwillingness to risk costs of federal re-registration requirements against potential revenue or perhaps refusal of registering the chemical. Implications of the continued transition from the diverse native and seedling trees to increased genetic uniformity of vegetatively propagated varieties on the ability to manage diseases and arthropods became ever more apparent, continuing a trend observed at least half a century earlier.

	J	F	M	A	M	J	J	A	S	O	N	D
Insect						YA		BA				
Secondary		Sc Ph	LT&D Ca Sa Ph			WC1 WW	WC2 WW C2	WC3 C3				
Primary					C1			S W				
Plant Pathogens				Pecan Scab*				Fall Foliage				
Horticultural				Rosette								
Pecan Stage	Dormant		Bud-Break		Pollina- tion			Nut Stage Water	Dough	Shuck-Split		
Month	J	F	M	A	M	J	J	A	S	O	N	D
Speed Sprayer Treatments:			H	H P	I P H			P	I P	I		

*Note: Humid Southeast may have up to 9 treatments for pecan scab control April-September (Miller et al. 1982).

[1]Key for abbreviations.

KEY FOR ABBREVIATIONS

BB - budbreak
D - dormant
LT&D - leaf tatterers & defoliators
Sc - scale
WC - walnut catepillar

C - pecan nut casebearer
DS - dough stage
M - mites
Po - pollination
Sp - spittlebug
WS - water stage

Ca - catacola
LC - leaf casebearer
Ph - phylloxera
S - hickory shuckworm
Sa - sawfly
SS - shuck split
WW - fall webworm

Figure 1. Phenology of pecan and pecan pest management practices[1].

CONSIDERATIONS IN THE MANAGEMENT OF PECAN DISEASES

Charles C. Reilly[1]

The control of diseases of pecan, *Carya illinoensis* (Wang.) Koch under current recommended management practices in the southeastern U.S. centers on the suppression of the pecan scab fungus *Cladosporium caryigenum* (Ell. et Lang.) Gottwald. There are, of course, other pathogens recognized as problems but these organisms are usually controlled with a fungicide spray application schedule such as that recommended in the Georgia Pecan Spray Guide (Ellis et al., 1990).

Notable of these "secondary" problems are powdery mildew, *Microsphaera penicillata* (Wall. Fr), which affects both foliage and fruit (Brenneman et al., 1988) and two foliar diseases, downy spot, *Mycosphaerella caryigenum* Demaree and Cole, and zonate leaf spot, *Cristulariella monicola* (Hino) Redhead (=*C. pyramidalis* Waterman and Marshall) (Littrell and Bertrand, 1981). Several other foliar diseases are of minor importance and in general the "secondary" diseases of pecan are controlled on an as-needed basis using orchard history and cultivar knowledge as guides.

The control of pecan scab is based on a calendar spray application program beginning at bud break and continuing through early August. Both a fruit and foliage phase of the disease exists and early control of this disease is imperative to reduce the detrimental effects. Pecan disease control accounts for the third largest market for fungicides in the United States preceded by peanuts and deciduous fruits (Littrell and Bertrand, 1981). The cost of fungicides and the perceived negative environmental effects of such chemicals has lead to the development of reduced spray treatments to control pecan scab (Gottwald and Bertrand, 1988; Wells et al., 1976). This in essence is the basis for chemical control of pecan diseases as presently recommended.

Misconceptions and inconsistencies continue to surface concerning pecan scab and disease control in general. First, pecan scab is not the only fruit disease that can lead to a total crop failure. Recently, phytophthora shuck and kernel rot and pecan anthracnose have been reported as serious threats to pecan production (Brenneman and Reilly, 1989; Reilly et al., 1989).

Second, inconsistencies as to the resulting effects of pecan scab infection on yield and quality appear throughout the literature. The data upon which the current abbreviated pecan scab control program is based, and other research, present strong evidence that scab infection occurring in mid- to late-season has no significant effect on quality or yield (Gottwald and Bertrand, 1983; 1988). These data appear to be ignored by some researchers and growers alike and much late-season damage is attributed to scab. This is not to imply that pecan scab control should be downplayed, but other diseases need to be recognized and effectively addressed.

New Problems, New Considerations

Phytophthora shuck and kernel rot is a newly recognized disease of pecan caused by *Phytophthora cactorum* (Lebert and Cohn) Schroeter (Reilly et al., 1989). It is a late season disease which occurs during prolonged periods of rainfall such as those caused by hurricanes in August and September. The pathogen is extremely aggressive and once established, rots the maturing fruit within 4-6 days. The pathogen has been isolated from soils of mature pecan orchards in South Carolina, Georgia, Florida, Alabama, Mississippi and Louisiana indicating potential problems throughout the southeastern pecan belt.

The biology of phytophthora shuck and kernel rot is not fully understood. The fungus is a water mold and requires free water for initial infection and spread to occur. Apparently, the fungus survives in pecan orchard soils from season to season, probably on pecan roots. Observations indicate the disease is more severe in irrigated orchards, but the method of movement of the fungus from orchard soil to the tree canopy is not known. Insects, mainly the pecan weevil [*Curculio caryae* (Horn)], have been considered as possible carriers of the fungus. Mechanical dissemination by sprayers or mowers may also move the fungus into the tree canopy.

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P. cactorum is capable of infecting pecan fruit throughout the season. Fruit inoculated during June, July or August remained on the tree as "sticktights". During the extensive outbreaks of this disease in 1988, small sticktights were observed to be the center of disease spread on individual branches. The spread was typical of rain-splash dissemination.

Protectant fungicides triphenyltin hydroxide or copper ion, have been used for control of the phytophthora shuck and kernel rot. Time of application, rates and intervals remain to be worked out.

Pecan anthracnose caused by *Glomerella cingulata* (Ston.) Spauld. and Schrenk was first reported in the United States on pecan in 1914 (Rand, 1914). This disease is distributed throughout the southeastern U.S. pecan belt and in recent years has been recognized as a problem, especially on certain cultivars (Brenneman and Reilly, 1989; Reilly, 1989; 1990).

The fungus will attack both foliage and fruit, however the foliage phase of the disease is seen only rarely in the field. Symptoms of the fruit phase of the disease appear late in the season on susceptible cultivars. *G. cingulata* sporulates during periods of rain and high humidity. Profuse salmon colored spore masses appear on the dark black, shiny, sunken lesions and are a distinct sign, characteristic of the disease. Beginning in late August, through harvest, lesions appear on the shuck, usually at the attachment end of the fruit. These lesions enlarge until the entire shuck is rotted. The rot extends throughout the shuck tissue to the nut shell. The pathogen can penetrate the shell and infect the kernel, with resulting damage to yield and quality ranging from "pops" in which the entire kernel fails to develop to "wafers" where various lesser degrees of kernel filling occur.

Initial control measures for pecan anthracnose were to evaluate fungicides that were effective in suppressing the disease. Effective control was not achieved using fungicides labeled for pecan disease control.

Current studies on overwintering, spore dispersal, infection periods and chemical control revealed some of the reasons for a lack of late season control of *G. cingulata*. The fungus over winters on the peduncles of the previous years crop (Table 1).

It appears that there is a range of reaction to *G. cingulata* as indicated by differences in percent sporulation of the different cultivars (Table 1). Field observations and numerous fungal isolations in our laboratory also support this contention. The optimum for sporulation of *G. cingulata* on peduncles of 'Wichita' pecan was 20°C, which is the approximate temperature that occurs during bud break and pollination (Figure 1).

Sporulation occurred in field plots during periods of rain from bud break through late June of 1990 (Figure 2). The early infections were detected in early May at the time of pollination on 'Wichita'. Infection courts were on the last vegetative bud just prior to the newly formed fruit cluster. Apparently, the primary infection occurs during this early season period and the fungus remains dormant until later in the season. This early season infection period is the critical period for disease control.

These conclusions are based on: 1) spore trap data (Fig. 2) indicating primary sporulation occurred during the early season, but not during symptom development in August and September; 2) disease studies reported on apple and papaya (Prusky et al., 1982; Taylor, 1971) documenting latent infection periods for *G. cingulata*; and 3) recovery from our laboratory isolations from symptomless fruit of *G. cingulata* throughout the season (Fig. 3).

During our studies of overwintering, a second fungus identified as a *Phomopsis sp.* also appeared on peduncles and may also be a pecan fruit pathogen. *Phomopsis sp.* has been associated with twig die back of pecan (Alfieri et al., 1984). The 'Moore' cultivar had significantly higher rates of phomopsis sporulation from peduncles collected at many sites throughout Georgia as compared to *G. cingulata* (Table 2). The *Phomopsis sp.* observed needs further study to clarify its role in pecan nut diseases.

With the recognition of new disease threats, new and realistic disease control strategies must be formulated. From existing information, it appears that pecan anthracnose becomes established early in the growing season. If this is true, both antracnose and scab may be controlled with a broad spectrum fungicide or a combination of compatible fungicides. Phytophthora shuck and kernel rot, in contrast, is definitely a late season disease with

a specific set of environmental requirements necessary for disease development. This should allow for an effective predictive model for disease control.

The challenges for disease research on pecans in the future therefore, must consider the entire disease complex, not just pecan scab. The appropriateness and effectiveness of existing fungicides must be reevaluated to consider the new pathogens and application technologies.

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Table 1. Sporulation of *Glomerella cingulata* and *Phomopsis sp.* on the peduncle of selected cultivars of pecan.

Location	Cultivar	Percent[a] Sporulation *G. cingulata*	*Phomopsis* sp.	Both
Albany Field 12	Wichita	44.1	10.7	2.2
Albany Field 12	Cherokee	8.5	52.0	5.2
Albany	Mohawk	4.1	22.5	20.4
Albany	Cape Fear	20.6	24.1	1.7
Albany	Desirable (Old)	6.4	38.3	6.4
Byron	Desirable (Young)	1.8	5.4	1.8

[a]Peduncles of the previous years crop were incubated for 6 days at 20C to induce sporulation.

Table 2. Sporulation of *Glomerella cingulata* and *Phomopsis sp.* on the peduncle of selected cultivars of pecan.

Location	Cultivar	Percent[a] *G. cingulata*	*Phomopsis* sp.	Both
Cordele	Wichita	31.5	13.1	5.6
Albany	Wichita	44.1	10.7	2.2
Byron	Moore	0	74.0	0
Albany	Moore	5.2	43.1	5.2
Leesburg	Moore	9.3	41.9	2.3
Marshallville	Success	6.1	47.2	2.7

[a]Peduncles of the previous years crop were incubated for 6 days at 20C to induce sporulation.

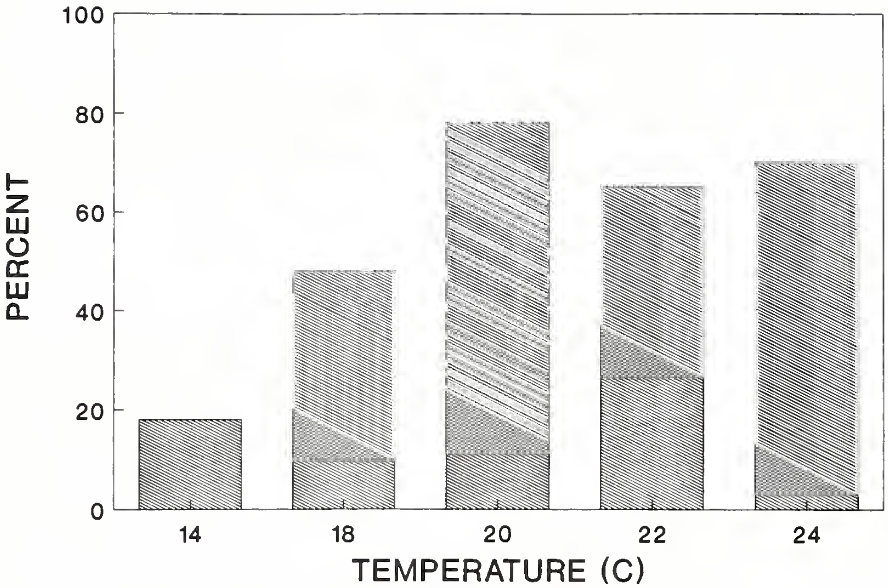

Figure 1. Optimum temperature for sporulation of *Glomerella cingulata* on peduncles of the previous year's crop on cv. Wichita. Peduncles were collected and placed in moist chambers at indicated temperatures, then rated after 7 days.

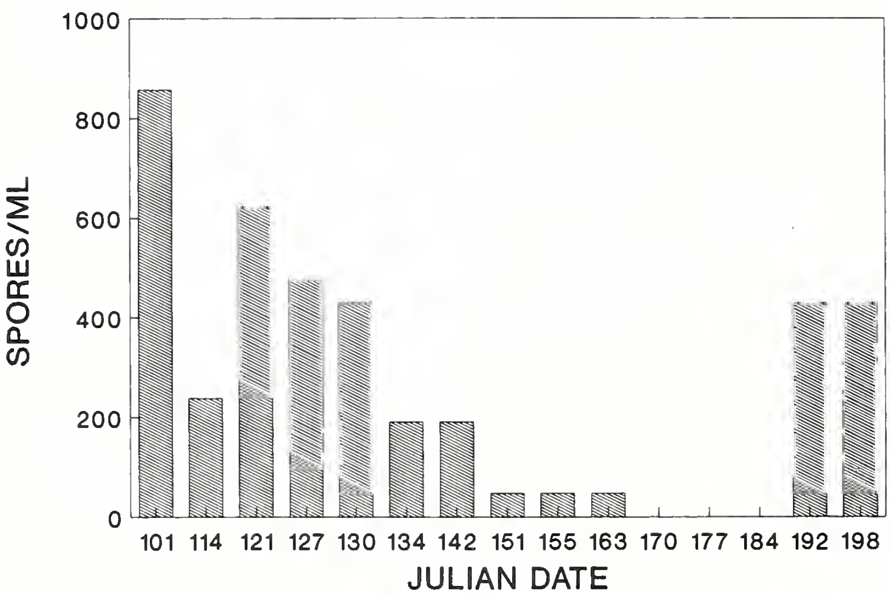

Figure 2. Spores of *Glomerella cingulata* collected during periods of precipitation in a commercial pecan orchard.

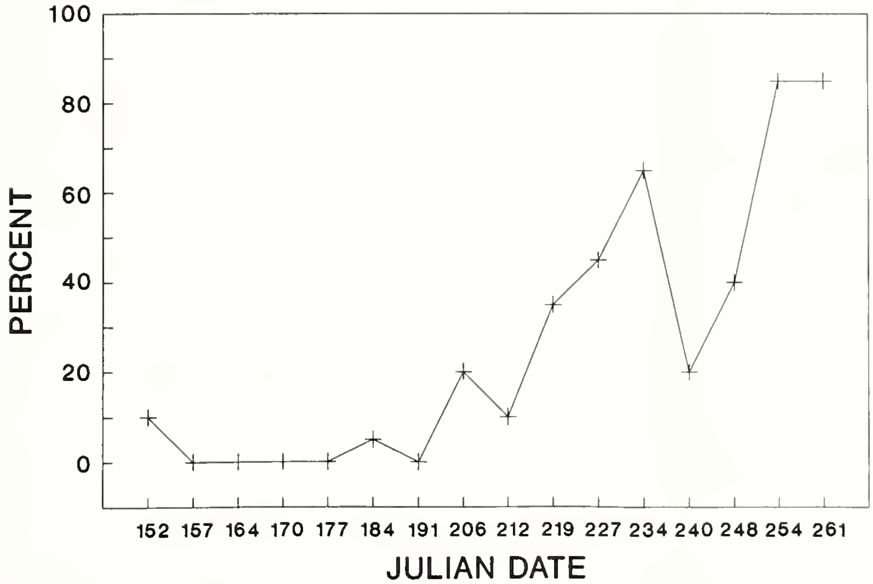

Figure 3. Isolation of *Glomerella cingulata* from pecan fruit. Symptomless fruits were surface sterilized then aseptically placed on plates of Potato Dextrose Agar.

CULTURAL PRACTICES

Darrell Sparks[1]

The purpose of this paper is to present a general overview and critique of selected cultural practices in pecan. Details of cultural practices will be presented in other papers of this conference. However, as many pecan-related businesses are marginally profitable and cultural practices form the core around which all pecan enterprises revolve, some of the major problems facing the industry as a whole and that need immediate attention by industry, research, and extension personnel will be initially addressed. These problems are the long-term financial risks incurred in orchard establishment, product promotion, and low yields per unit area of land.

CRITICAL INDUSTRY PROBLEMS

Orchard Establishment Costs

Establishing a pecan orchard is an expensive, long-term investment with establishment costs averaging $6,000-$8,000 per acre. Establishment cost is defined as land cost plus dollars spent between planting until the first year the orchard produces a return in excess of annual operating costs. The first return can be expected 10-15 years after planting. The exact time will vary depending on the quality of the grower, soil moisture, and some luck. Fifteen to 20 years are normally required to regain the investment. The large investment presents an economical barrier to entry and greatly increases the risks, but affords some stability for the industry. Initial decisions such as site selection, spacing, type of irrigation system, and cultivars directly impact the probability of the success of the orchard. Site and cultivar selection are two factors that can make or break the success of an orchard.

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Ineffective Marketing Strategies

The lack of an effective marketing program is the single most important factor responsible for the financial problems of today's industry. The positive attributes of pecan have never been promoted to the consumer in a highly visible advertising campaign. In contrast, other nut industries (i.e., almonds and walnuts) have promoted their products sufficiently to allow substantial increases in production at the expense of shares of the pecan market (Anon. 1978).

The general consensus within the pecan industry is that historical differences resulting in distrust between processors and growers has been the primary reason for the failure to develop a successful marketing program for pecans. The situation has been accentuated by lack of cooperation and intensifying market competition between growers in the eastern and western pecan regions of the U.S. At the moment, and for the first time in the history of pecan, all groups are working together in an effort to get the Pecan Promotion and Marketing Act passed in the United States Congress. This cooperation was prompted by low profits or losses to both grower and processor.

In the past 12 years, monies for advertising pecans have depended on voluntary contributions to the National Pecan Marketing Council. Lacking consistent funding, the promotion of pecan has been sporadic. In addition, advertising has been managed by individuals lacking the professional training and repertoire of skills essential for success in the complex and competitive world of advertising. Approval by the United States Congress of the Pecan Promotion and Marketing Act should improve the funding situation. Careful selection of a professionally trained advertising coordinator with adequate experience should help educate the consumers, both nationally and internationally, as to the merits and value of pecans in the diet.

Low Yield

Yields are low. This is reiterated by the fact that pecan is one of the very few tree crops in which yield per acre is measured in ***pounds*** instead of ***tons***. The average yield is a paultry 850 pounds per acre in the world's center for pecan production found in a 50 mile radius of Albany, Georgia (Weber 1991). At $0.70 per pound, the gross return per acre is $595. Depending on the grower, operating costs range from about $550-$750 per acre. Thus an average grower can expect at best only a small profit. The maximum

potential yield is also very low when contrasted with many other nut crops. Depending on the climatic region, maximum long-term yields range from about 1,500-2,000 pounds per acre. However, very few growers achieve these yields on a long-term average. Yields of 3,000-4,000 pounds per acre are unrealistic with existing cultivars and production technology. Claims of yields of thousands of pounds per acre most often occur in sales prospectus, in new cultivar releases, during the "on" year or in small plots. However, such large yields have never been obtained in large acreages on a long-term average. For the present and probably for many years in the future, the pecan industry must struggle with low yields. Consequently, the grower, researcher, and extension personnel will have to continue to develop strategies to cope with low yields.

Cutting operating costs is often suggested as a means of compensating for low yields. To a large degree, many of the costs in pecan are fixed as is best illustrated by cultural practices following a crop lost from a late spring freeze. In this situation, the first reaction by the grower is that since there is little or no fruit some cultural practices can be omitted and thus financial loses can be minimized. However, when critically analyzed, very few costs can be eliminated (with the exception of harvest) that will not translate into reduced yields in subsequent years. This is the case because practices such as irrigation and control of foliage pests must be continued if yield and quality are to be maximized the following year. The major means of "cutting costs" to compensate for low pecan yields is through the proper timing of cultural practices for maximum response. For example, if a spray for nut casebearer is applied at the proper time at adequate insecticide concentration, fruit loss is minimized at the minimum cost. If sprays are not properly timed and/or insecticide concentration is too low, damage occurs and additional cost is incurred from re-spraying. Entomologists have developed and are continuing to improve spray programs to control insect pests by determining the most effective time for spray application. Examples include the heat unit model for nut casebearer (Ring et al. 1983), pheromone traps for shuckworm (Smith et al. 1987), and scheduling sprays for leafminers (Heyerdahl and Dutcher 1985). Pathologists need to develop more effective guides for scab control. Scheduling scab sprays could be improved by emphasizing the importance of leaf wetness and stage of leaf and fruit growth to scab infection. Data for leaf wetness are available (Latham 1982) but are apparently not used. Leaf wetness may be an especially useful tool now that "back action" is available with Orbit. Back action refers to the ability of the fungicide to inactivate fungal infections that occurred 1-3 days prior to spray applications.

Extension horticulturists need to furnish the grower with available information on scheduling irrigation. Scheduling irrigation by monitoring infrared canopy temperatures has possibilities (Garrot et al. 1989, Sammis and Herrera 1989) and scheduling by pan evaporation works very well (Weber 1991, Worthington et al. 1988). Preharvest operations, such as orchard floor preparation, can be more accurately scheduled by predicting nut maturity date using heat units (Sparks 1989b). Leaf analysis, which has been developed to a high degree (Sparks 1989a), can be used to determine fertilizer requirements. Added precision in preharvest operations and fertilization translates to reduced costs.

A second avenue of coping with low yields is to increase the selling price of pecans by stressing the superior value of pecans to consumers in contrast to other nuts. For example, a strong case can be made for the pecan as a health food. Oklahoma pecans are currently promoted, in part, based on health benefits. With the current consumer attitude, the zero cholesterol level of pecan is an especially creative approach (Childs 1991). The nutritional value of nuts has been recognized for close to 100 years. In 1908, nuts were recommended for vegetarians as a meat substitute due to their high protein content and for diabetics due to their low sugar content (Jaffa 1908). J. H. Kellogg, a diehard vegetarian, was very active in promoting nuts as a source of protein (Kellogg 1920, 1922, 1926). The unsaturated fats content of pecans should be appealing to health conscious consumers. During the depression of the 1930's, pecans were reportedly selling for $0.60 per pound in Mexico, because Mexicans believed that pecan was an aphrodisiac. In 1987, the ***Saturday Evening Post*** was giving one pound of pecans to new subscribers. The advertisement claimed that pecan was high in Zn and that Zn was a factor in preventing prostate problems in men. Pecans are also valuable in preventing certain types of arthritis. Research is needed to determine the validity of some of these claims, but in the meantime, the nutritional information available should be used to maximum advantage as with the promotional program in Oklahoma (Childs 1991). Promoting pecans as a health food may do more to increase the market value of the nut than any other single factor.

Since the late 1800's, attempts have been made to increase yields by cultivar improvement. However, except for initial selections ('Desirable', 'Schley', 'Stuart' and 'Western') made near the turn of the century, a long-term increase in yield due to cultivar improvement has not been demonstrated. Instead, yield increases during the past 60 years appear to be due entirely to improved cultural practices. The same situation appears to be true for deciduous fruit tree crops in general.

The difficulty of increasing yields in deciduous fruit crops by cultivar improvement is due to a large extent to an inverse relationship between fruit number and quality (Dodge 1946). Genetically increasing the number of fruit per tree is relatively easy, but maturing the fruit with the desired level of quality is difficult. This problem is circumvented by thinning in peaches and apples. However, chemical fruit thinning in pecan is not presently feasible (Sparks 1986) and consequently, nut quality decreases with tree maturity in prolific cultivars (Sparks 1990). Mechanical fruit thinning (Smith and Gallott 1990) may prove to be a means of alleviating this problem.

The major emphasis in pecan breeding programs has been on developing precocious cultivars. The close link between precocity and prolificness was recently demonstrated (Sparks 1990). When a precocious cultivar is a young tree, there is ample leaf surface to supply the nutritional requirements for developing fruit. However, as the tree matures, the leaf to fruit ratio declines and there is a concomitant decline in the quality of nut produced. Classical examples of this relationship are 'Chickasaw', 'Cherokee', 'Mohawk', 'Barton', and 'Cheyenne'. Prolific cultivars that do produce acceptable nut quality as the tree matures have a nut that is too small to sell for a good price. Examples are 'Caddo', 'Sioux', and 'Tejas'. The net result is that breeding programs have failed to place sufficient emphasis on market value of the nut which is largely dictated by size and quality. The dramatic effect on the market value of the nut can be illustrated by comparing the per acre value of 'Western' vs. 'Desirable'. Assume a well-managed 'Western' and 'Desirable' orchard will yield 2,000 and 1,400 pounds of nuts per acre, respectively. Assuming 'Western' nuts sell for $0.70 and 'Desirable' for $1.10 per pound, the gross return per acre for 'Western' (2,000 lbs/acre x $0.70/lb = $1,400/acre) is less than 'Desirable' (1,400 lbs/acre x $1.10/lb = $1,544), in spite of the fact 'Desirable' produces 600 pounds of nuts per acre less than 'Western'.

On the positive side, L.D. Romberg may have made two notable advancements in pecan breeding, 'Wichita' and 'Pawnee'. 'Wichita's performance as a young tree has been outstanding. One long-term comparison by a grower indicates that 'Wichita' will outproduce 'Western' by about 17%. As a young tree, 'Wichita' produces good quality nuts even with a heavy fruit set. Nuts mature fairly early with acceptable nut size; giving 'Wichita' nuts a high market value. The drop of pistillate flowers [first drop, Sparks and Madden (1985)] is sensitively regulated by shoot vigor, thus giving the grower extra control over production. Unfortunately, the fruit tends to split during the water stage of development following rain and accompanying high humidity. The tree is also very susceptible to freeze injury. For these reasons, 'Wichita' is best suited to arid regions with relatively mild winters. However, 'Wichita's' performance as a mature tree has not been fully evaluated and in some situations, nut quality can be very poor. Limited observations suggest 'Wichita' will be difficult to manage as a mature tree.

'Pawnee' is unique in that it produces a large, early maturing nut that is well filled and has a light colored kernel. Consequently, the market value for 'Pawnee' nuts is exceptionally high. Like 'Wichita', 'Pawnee' has not been tested as a mature tree. Once the tree matures, alternate bearing and nut fill may be a problem due to the large number and size of nuts in each cluster. Regardless of possible negative characteristics of mature trees, 'Pawnee' is potentially an excellent cultivar for use in a breeding program in which early nut maturity of a large, light colored nut is a major objective.

Another major deficiency of pecan breeding programs, including those supported by USDA and by state universities, has been the general failure to test new cultivars against the industry standards-'Desirable', 'Stuart', and 'Western'. Because 'Desirable' is usually considered to be the best of the three; comparative tests between 'Desirable' and potential new cultivars should always be conducted before releasing a new cultivar. A minimum of 10 and preferably 20 trees of each cultivar should be used in any comparisons. Historically, pecan cultivars have not been tested as mature trees prior to release which has proven to be a major mistake. This has been a mistake mainly because many of the cultivars failed to produce quality nuts once the tree reached maturity. Examples are 'Mahan', 'Mohawk', 'Chickasaw', 'Cherokee', 'Mobile', 'Moore', and many others.

Minimum, but high priority, objectives of any breeding program should be to develop cultivars that produce nuts with a maximum market value. Nuts with high market value must meet the following criteria: 1) size must be large (ca. 50 or less nuts per pound); 2) maturity must be early (equal to or before 'Stuart'); and 3) kernels must be light colored. Another criterium that must be fulfilled is for the tree to produce only one to three nuts per cluster in order to ensure maximum nut fill and return bloom the following growing season. These objectives would result in an improved 'Desirable' which already produces a cluster with about one to three large nuts that have good kernel color, but the nuts of 'Desirable' mature late. Crosses between 'Desirable' and 'Pawnee' may be especially advantageous because of the possibility of the introgression of genes for earliness from 'Pawnee' into the 'Desirable' genome or alternatively, the introgression of genes for a small number of nuts per cluster from 'Desirable' into the 'Pawnee' genome.

BASIC CULTURAL PRACTICES

The ability of a pecan tree to support nut production is governed by the efficiency of the leaves and the leaf area per fruit. These parameters are regulated by both genotype and environment. Within the boundaries of the inherent genetic makeup of the tree, the environmental elements most important to pecan production and which the grower can regulate to some degree are sunlight reception, soil moisture, diseases and insects, and mineral nutrition (Sparks 1975).

Sunlight

The effects of maximizing sunlight reception are illustrated by the fact that a solitary tree in an open field (sunlight exposure is maximum) is typically more productive than a single tree in an orchard. Similarly, border trees are more productive than trees within the interior of the orchard. Trees surrounding an opening created by a missing tree are more productive than trees without the opening. In spite of these striking observations, very little work has been done on the sunlight requirements of the pecan. The most definitive work is that of Hinrichs (1961). Inadequate sunlight from within and between tree shading is a major problem in many orchards. The problem can easily be minimized by selective limb removal from temporary trees (wisking) or by selective removal of these trees (Weber 1991).

Soil Moisture

The major environmental factor over which the grower has control for optimizing pecan production is soil moisture (Weber 1991). Because of the dominating effect of water and the high production cost of pecans, pecan production should not be attempted without irrigation. In arid regions, this obviously goes without saying, but, in the humid Southeastern United States, irrigation is also essential. In the Southeast, insufficient soil moisture can occur in any month, but is most likely to happen in September, the most critical period for kernel development. Inadequate soil moisture in September tremendously suppresses kernel development (Andrews and Sherman 1980), typically seen as poorly filled kernels at harvest. Maintaining adequate soil moisture in this month can, over many years, easily be expected to increase marketable yield by 25%. Insufficient soil moisture during kernel development is the dominant factor contributing to poor kernel quality in the Southeast. To grow pecans in this region without irrigation greatly increases the risk of failure.

The two most common types of irrigation systems used in pecan orchards in the Southeastern United States are drip and solid set sprinklers. Some orchards are irrigated by solid set sprinklers, but most (ca. 90%) are irrigated by drip (Hubbard et al. 1988). Solid set, when scheduled by pan evaporation, works very well. With many drip systems, however, the maximum water output potential is inadequate for peak periods of demand, resulting in significant yield looses. Yield records maintained by growers using adjacent drip and solid set sprinklers verify that maximum vegetative growth and yield cannot be consistently obtained with the drip systems currently installed in most orchards. These observations conflict with research data which indicate that yields from solid set and drip are the same (Daniell 1978, 1985). Probable reasons for this conflict is that the irrigation research was conducted with young trees which have a relatively low water requirement (Worthington et al. 1988); and in addition, the experimental design may have been inadequate. Another major problem with drip irrigation is that maintenance costs are great.

As a general rule, in a 500-acre orchard, one man is needed during the growing season to keep a drip system in optimum operating condition. Considering insufficient water application and the additional maintenance of a drip system, installation of a solid set sprinkler system is a much more sound long term investment.

Diseases

The two major pecan diseases are downy spot (*Mycosphaerella caryigena* Demaree and Cole) and scab [*Cladosporium caryigenum* (Ell. and Lang.)]. Downy spot is the major disease in semi-arid regions and scab is the major disease in humid regions. There are other diseases of pecan but most are controlled by fungicides targeted for downy spot and scab (Graves and Coats 1989). When downy spot and scab are not controlled, other diseases can become a problem. the classical example is the outbreak of Phytophthora shuck and kernel rot that occurred in the Fort Valley area of Georgia in 1988 (Reilly 1989). The severity of kernel rot among orchards was inversely related to the number of fungicide sprays that had been applied during the season.

Scab probably causes more damage in the humid Southeastern United States than all other diseases and, possibly all insects, combined. The severity of scab as a pecan disease can be inferred from the many papers that have documented losses in yield and discussed control measures (see Proc. SE Pecan Grow. Assn.). Much of the dramatic increase in Georgia's pecan yields during the past 25 years can no doubt be attributed to control of scab. In spite of the well known and documented destructive effect of scab since the early part of this century, scab had a disastrous effect on Georgia pecan yields during 1989. Two major factors were responsible for its widespread severity. One, there were approximately 37 inches of rainfall from April-August which was well distributed throughout the season making conditions ideal for infection. Two, the economics of production during the years preceding 1989 had resulted in changes in control procedures for scab. Due to increased fungicide costs and low nut prices some growers reduced the fungicide concentration in the spray solution. In addition, many growers switched to the practice of applying alternate, one-sided sprays. With this practice, the trees are sprayed on one side only with the next spray being applied on the opposite side of the tree and the alternating is continued throughout the season (Reilley 1990). This program appeared to work because of low scab pressure for several years preceding 1989. Needless to say, the practice did not work well in 1989. Scab was also widespread in 1990. The two consecutive years of severe scab have prompted some individuals in the pecan industry to request more research on scab. While more research on alternate methods of scab control as well as on the biology of the scab fungus is needed, growers need to do a better job of using the information that is already available. Also, there is considerable confusion concerning the amount of fungicide applied on a per acre basis vs. the concentration of fungicide applied in the spray solution. In an attempt to improve coverage, some growers have diluted the fungicide to the point that its effectiveness is marginal or essentially ineffective. In addition, research directed towards determining how long into the growing season the fungicide needs to be applied should be re-investigated. The research on this subject (Bertrand and Gottwald 1984), which was conducted in relative dry seasons, has apparently resulted in some growers terminating scab sprays too early in the season.

Insects

There are four major fruit insects. These are pecan nut casebearer (*Acrobasis nuvrorella* Neunzig), plant bugs [stink bugs (*Nezara viridula* (Limnaeus); (*Euschistus servus*) and leaffooted bug *(Leptoglossus phyllopus* (Linnaeus)], hickory shuckworm [*Laspeyresia caryana* (Fitch)], and pecan weevil [*Curculio caryae* (Horn)]. Each of these insects can cause the fruit to abort and/or reduce the market value of the nut. Damage from nut casebearer (Coppock 1989), shuckworm (Calcote et al. 1984), and weevil (Payne et al. 1985) is well documented. Although the destructiveness of plant bugs has long been known (Adair 1932), observations suggest that their damage may have been under estimated relative to the other insects. Fruit drop during the water stage of development in many cases (especially in 'Schley') appears to be due more to plant bug damage than to fruit split or other physiological disorders. Observations also indicate that the threshold level for these bugs deemed acceptable before applying an insecticide is much too high.

The three major leaf insects are black aphids [*Melanocallis caryaefoliae* (Davis)], leafminers (primarily blotchy [*Lithocolletis caryaefoliella* (Clemens)] and serpentine [*Stigmella juglandifoliella* (Clemens)], and potato leaf hopper [*Empoasca fabae* (Harris)]. Black aphids and leafminers can cause severe defoliation. The adverse effect of defoliation from black aphids on return bloom was demonstrated more than 50 years ago (Moznette 1934) and the experimental effect of leaf removal that would simulate black aphid induced defoliation has been shown repeatedly to suppress nut quality, return bloom and yield (Sitton 1931, Hinrichs 1962, Sparks and Brack 1972, Worley 1979). As a consequence, significant defoliation by insects is detrimental to nut production. Of these three

insects, black aphids are by far the most important because they occur more frequent and late season infestations almost always results in defoliation. Controlling this insect has been a major factor contributing to the increase in Georgia's pecan yields over the past 25 years. Although defoliation from leafminers does not occur often, when it occurs it can be extensive. Potato leaf hopper damage appears to have become a problem with the advent of integrated pest management. Prior to the use of integrated pest management programs, leaf hoppers were controlled by insecticides targeted for other pests (e.g., primarily aphids). Extensive damage from potato leaf hopper occurred in Georgia in 1986. In severe cases, leaf area was reduced by an estimated 75%. 'Desirable' and 'Western' appear to be especially susceptible to potato leaf hopper.

In 1984 and 1985, yellow (*Monelliopsis nigropuncta* Granousky) and green [*Monellia caryella* (Fitch)] aphids became a major concern to pecan growers, especially to those in Georgia. During those two years, aphid infestations were very heavy and widespread. Also in 1984 and 1985, nut quality was generally very poor. The poor quality was generally associated with heavy aphid infestations and, as a consequence, aphid control became a major concern of pecan growers and research and extension personnel. Although aphids no doubt exact their toll (Wood and Tedders 1982), the association of poor quality nuts with aphids was confounded with dry Septembers in both 1984 and 1985. Kernel development is a function of soil moisture in September (Andrews and Sherman 1980). Orchards that were well-irrigated in 1984 and 1985 produced good quality nuts even with significant aphid infestations present. This strongly suggests that most of the damage in other orchards was due to water stress rather than aphids.

Although the magnitude of the effect of aphids on reducing yield and quality may be questionable, there is little doubt that the aftermath of aphids, i.e., sooty mold, is detrimental. The shading effect of sooty mold on the leaf (Tedders and Smith 1976) and the accompanying suppression of photosynthesis is well documented (Wood et al. 1990).

Low aphid populations are generally considered to be closely related with high populations of beneficial insects. Considerable research has been conducted on the control of aphids *via* increasing the population of beneficial insects (Bugg and Dutcher 1989, Dutcher 1990, Liao et al. 1984, Edelson and Estes 1987, Mizell and Schiffhauer 1987, Tedders 1983, 1986, Tedders et al. 1989). If aphid populations are closely associated with beneficials, spraying with pesticides might be expected to make aphid control more difficult to achieve. In this regard, the fact that Pierce (1957) did not list green and yellow aphids as serious insect pests in unsprayed pecan orchards is perhaps worthy of note. Likewise, the idea that spraying can increase aphids is supported by the practice among growers of postponing insecticide sprays as long as possible. Once spray is instigated, aphid control becomes more difficult and in some years becomes a season-long battle. This observation, and the general emphasis on utilizing beneficial insects, has led to the limited practice of not applying pesticides targeted for aphids. Instead, the aphid populations are allowed to peak and decline. Thus far, this practice has been highly successful in one pecan orchard in the semi-arid west and insecticides targeted for aphids have not been applied for four consecutive years. Aphid populations come and go but yields and nut quality have remained high. Likewise, sooty mold has not been a major problem. Limited experience in Georgia suggests that similar results can be achieved, although the success may be less striking in some orchards because of the necessity to spray for the pecan weevil and other pest insects which can result in resurgences of aphids (Dutcher and Payne 1983). Controlling other pecan pest insects is the complicating factor in aphid control in that pesticides targeted for other insects also kill the beneficials. In this regard, Mizell and Schiffhauer's evaluation (1990) of the various insecticides on beneficial insects is timely.

If the assumption is accepted that utilizing insecticides for aphids increases the total aphid population over the season, then sooty mold accumulation may also be enhanced from excessive pesticide use. If so, careful use of insecticides would result in less sooty mold, thus reducing the indirect effect of aphids on nut yield and quality.

The research on the effects of aphids on pecan growth, nut yield, and quality (Dutcher 1985, Dutcher et al. 1984, Stone and Watterson 1981, Tedders and Wood 1985, Wood et al. 1987) to date either shows no effect or else the results are inconclusive. Effects of aphids on pecan need to be reevaluated utilizing appropriate controls [e.g., outlined by Mizell (1990)]. Furthermore, confounding variables, such as cover crops and

other pest insects, should be excluded. In addition to controlling other insects, other critical factors affecting pecan performance (diseases, sunlight exposure, soil moisture, and nutrition) should be strictly controlled. Finally, the direct effect of aphids vs. their indirect effects on sooty mold on tree performance needs to be separated. The basic question is not if the aphids do damage, but instead does spraying enhance the damage *via* destruction of beneficial insects and increased sooty mold production. At the moment, the "aphid problem" may be one simply created by poor management.

Nutrition

Although all the nutrients essential for other plants are likewise essential for pecan, nutritional problems in pecan basically center around N, P, and K, and Zn. Nitrogen, P and K become especially critical once the tree reaches reproductive maturity. All three nutrients are suppressed strikingly in leaf tissue by fruiting and, for this reason, N, P and K have been proposed to be contributing factors to the irregular or alternate bearing habit of pecan. That is, N, P, and K are suppressed during the "on" year of fruiting and replenished during the "off" year in the same manner as carbohydrates (Sparks 1985). Experiments to test this hypothesis have failed because N, P, and K have not been simultaneously increased to an optimum level. Thus, the idea remains a hypothesis. The failure to increase N, P, and K simultaneously points up the number one problem in pecan nutrition; that is, an inadequate understanding of factors influencing uptake of the nutrients from the soil. In most orchards, more fertilizer is probably being applied than will be utilized by the tree, but the amounts applied are apparently needed to override the factors interfering with uptake. Preliminary data indicate that time of fertilizer application has a dominant effect on tree response (Sparks 1989a). Timing of application needs further study. Also, a better understanding of competitive effects between various nutrients on absorption and soil factors, such as pH, influencing uptake is needed. Because fertilizer is a major expense in pecan production, improving the efficiency of nutrient uptake will result in immediate savings to the grower.

Historically, one of the major weaknesses of nutritional research in pecan has been the lack of an adequate plot size and the confounding effect of alternate bearing. As a result, much of the work is inconclusive and, in some cases, incorrect conclusions have been drawn from the data. Ideally, 15-20 trees should be used per treatment and young trees, which have less alternate bearing, make better experimental material.

Nitrogen applications vary from about 100 to 250 pounds per acre. High applications should be applied only to nonprolific cultivars and then only if soil moisture is maintained at an optimum level. Otherwise, more fruit will be set than the tree can adequately develop (Sparks 1989a). The reason this will occur is because a primary effect of N is to increase pistillate flower formation. Contrary to widespread belief, N application, above the visible deficiency range, has very little effect on shoot growth. Vegetative growth, and thus leaf area, is governed primarily by soil moisture (Sparks 1989a). Unfortunately, the concept that N is the major growth promoting factor has been elevated to a horticultural principle without supporting data. Consequently, N becomes a "cure all" and more N is often recommended when low vigor is due to other causes. There are two other misconceptions concerning N. One, N application, especially late in the growing season, will increase the susceptibility of the tree to winter injury and two, N application delays nut maturity. There are no data to support either supposition. In fact, winter injury is not increased by late N applications (M.W. Smith, personal communications 1990) and time of fruit maturity in pecan is directly dependent on heat units in the springtime (Sparks 1989b). However, as in the case of N vs. tree vigor, the ***idea*** that N increases winter injury and delays nut maturity have also unfortunately been elevated to horticultural principles.

The optimum leaf P level has been proposed to be 0.19 to 0.22% (Sparks 1988). Based on this range, P is deficient in many orchards. Also, in these orchards, the proposed range, 0.19-0.22% leaf P is mostly academic simply because we do not know how to increase P in the leaf. Thus, the most important problem in P nutrition is uptake.

Potassium nutrition of pecan has been reviewed (Sparks 1985). Many growers, especially those in the arid pecan regions of the United States, hesitate to apply K in pecan orchards. This hesitation exists in spite of the relationship between K and winter injury (Sharpe et al. 1952), the depressive effect of N on K uptake (Gammon and Sharpe 1959), the depleting effect of fruiting on leaf K (Sparks 1977) and it's possible role in

alternate or irregular bearing of pecans (Sparks 1985). Premature defoliation from N-K imbalance (Sparks 1976) remains a problem in many young orchards. Premature defoliation suppresses growth and predisposes the tree to winter injury.

At one time, Zn deficiency was the number one problem in the pecan industry. The solution to this problem apparently resulted in a dramatic increase in nut production (Sparks 1987). Because of the deleterious effects and widespread occurrence of Zn deficiency, extension and growers placed top priority on Zn management. In most acid soils, correction could be made from soil application. Once deficiency was corrected, soil applications were often continued on fixed schedules regardless of need. Thus, the approach to Zn nutrition often approximated that of a macro-nutrient. As a consequence, soil Zn levels in many orchards are very high and in some orchards as high as 300 pounds per acre. Sometimes trees in these orchards have "mouse ear" indicating an association with high soil Zn. Before the advent of adequate spray equipment, correcting Zn deficiency in pecan orchards in alkaline soils was difficult because of ineffectiveness of soil application. Once improved sprayers were available, emphasis was placed on foliar application to trees growing in alkaline soils. In recent years, foliar application has also become widespread in orchards growing on acid soils. This has occurred because of the increased expense of Zn for soil application. The incentive to apply foliar Zn to trees growing in acid soils is also enhanced by the fact that scab sprays are applied routinely and Zn can be conveniently tank-mixed with the fungicide. Thus, the cost of applying Zn is material cost only. This practice no doubt results in unnecessary Zn application in some orchards.

The critical level for leaf Zn is about 14 ppm on an individual shoot basis (Hu and Sparks 1990, 1991). However, because of the wide tree to tree variation in Zn (Worley et al. 1972) and the method of leaf sampling, the critical leaf value for trees in acid soils is 50 ppm (Sparks and Payne 1982). This value is lower than the 80 ppm leaf Zn proposed by Storey for high pH soils (1989). In theory, the critical value for trees on alkaline soils should be lower, not higher, than for trees growing in acid soils. This should be the case, because under untreated conditions, trees growing in alkaline soil are uniformly low in Zn; whereas, in an acid soil, one tree may be deficient while adjacent trees may be normal. Consequently, in an acid soil, a higher critical value is required to compensate for increased variability. A lower critical leaf Zn for trees in alkaline soil is also supported by research. In El Paso, TX, neither a yield nor nut quality response was obtained when leaf zinc was at least above 39 ppm (Malstrom et al. 1984). Similarly, in Arizona (Kilby 1985), leaf area per leaflet did not increase as leaf Zn increased from 25 to 223 ppm. However, from a practical standpoint, and under sprayed conditions, the critical value is relatively unimportant simply because adequate Zn is readily supplied to the trees by spraying (2 lbs $ZnSO_4$/100 gal water) at appropriate intervals with adequate coverage. That is, coverage and scheduling are the dominant factors in the management of Zn nutrition.

In high pH soils, Zn sprays have to be applied regardless of the need for insect and disease sprays. In the absence of insects and diseases, economical alternatives to foliar applied Zn sprays would certainly reduce production costs.

Challenges

The number one horticultural challenge in pecan culture is to keep the tree growing vigorously once it matures or more specifically maintain the tree in a young state. Because of a large leaf area per fruit, young trees produce high quality nuts both in terms of size and well developed kernels and alternate bearing is not a problem or else is minimal (Sparks 1975). As the tree matures, maintaining high vigor is difficult because shoot growth declines due to an increasing percentage of shoots that set fruit and to the maintenance of a larger mass of wood.

Pruning will restore vigor in mature pecan trees. However, because nut yield is a direct function of tree size (Boudreaux et al. 1985, Ware and Johnson 1957), removing a portion of the tree by pruning would be expected to reduce nut yield as is the case (Worley 1991). With prolific cultivars, which upon tree maturity often fail to produce quality kernels (Sparks 1990), pruning would, in theory, increase the leaf area per fruit and result in a better quality nut. The net result would be to increase marketable yield as suggested by the pruning study with 'Mahan' (Amling and Dozier 1969). However, in most pecan growing regions, hand pruning as done by Amling and Dozier is cost prohibitive.

Mechanical hedging to revigorate the tree and improve nut quality in 'Western' was initiated by Stahmann Farms 20 or more years ago. Hedging has proven to have at least two major problems. One, initial reduction in yield occurs and, two, in cultivars with closed canopies; e.g., 'Wichita',

the interior to the canopy shades out resulting in further reduction in yield. Hedging would probably be more successful if some of the multiple branches resulting from the cuts were thinned out. This requires hand labor which in most situations is too expensive. The practice of hedging is no longer recommended (Herrera 1989).

Chemical fruit thinning will help maintain shoot vigor and nut quality by increasing the leaf to shoot ratio. However, there are a number of inherent problems associated with chemical thinning (Sparks 1975) and presently, chemical fruit thinning is not feasible (Sparks 1986). Fruit thinning by mechanical shaking off a portion of the fruits (Smith and Gallot 1990) is a more realistic approach. Mechanical shaking, in contrast, to chemical thinning, would allow the grower to individually select the trees to be thinned. At the moment, mechanical thinning may prove to be a significant breakthrough for pecan production.

For now, the major means of maintaining vigor in pecan is by keeping soil moisture at an optimum level. Observations show that vigor can be greatly increased on old trees if soil moisture is kept constantly at a sufficient level. However, as yields increase with this improved shoot vigor, shoot vigor begins to decline once fruit production reaches a high level. After about 4-5 years, the tree reverts to an off or reduced year of production and the cycle of vigorous growth must be reinitiated. If leaf area per fruit can be economically maintained at an optimum level, marketable yield per tree and acre would increase substantially; thus, the low yield problem would be minimized.

The challenge facing the pecan breeder is to develop a cultivar superior to 'Desirable'. Most probably, if this goal is accomplished, significant changes in pecan fruit growth and physiology will be required. A more efficient leaf that is shade tolerant, a substantial lower oil content in the kernel, and/or a longer period of kernel development are possible approaches.

The most important challenge facing the pecan industry as a whole is the promotion of its product. To make promotion a success, the industry will have to organize and cooperate on an unprecedented level, hire competent people, and fund research essential to promotion.

The Environmental Protection Agency has created two challenges. The first challenge is the apparent threat of the EPA itself. Although the EPA may mean well, the agency, in general, has an inadequate understanding of agricultural crops and the economics of agriculture. The EPA's hovering threat of removing pesticides from the market drives up the cost of existing pesticides and, at the same time, makes the chemical companies very hesitant to develop new products, especially for minor crops like pecan. The net result is production costs to the grower are increased. The removal and expectations of further pesticide removal from EPA approval has created the second challenge; that is, alternative methods of pest control. Unfortunately, losses in chemicals are preceding progress being made in alternate pest control methods.

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PECAN ORCHARD MANAGEMENT

Robert E. Weber[1]

As a manager of properties (which range from 2,500 acres to 28,000 acres) for absentee landowners. I deal primarily with pecans, peanuts, corn, cotton, and timber. During the past 40 years I have gained a great deal of knowledge about all of these crops, but today I will confine my discussion to pecan orchard management in Southwest Georgia. I work in Southwest Georgia where pecans are an especially important crop. In Dougherty County, where I live, there are 20,000 acres of pecans with an average yield of 850 pounds per acre. Most of the pecan trees were planted from 1915 to 1925 so the trees are 65 to 75 years old. Most of the present orchard management is with varieties, soils and tree spacings that were determined 70 years ago. There have been a few new plantings in the past 20 years. Many of these new plantings were of the Indian varieties which have not proved to be good varieties for Southwest Georgia.

Orchard management is the use of all available information about pecans to develop a management plan that will achieve the most profitable long-term monetary return. To be successful in orchard management one must be familiar with pecans and their basic requirements. The first four basic requirements are a) topography of the land, b) soils and drainage, c) growing season, and d) water supply. These four basic requirements determine if pecan trees can be successfully grown. They are inherent to the location of the orchard. I would not attempt to manage an orchard if these requirements were unfavorable.

Other requirements for successful production are a) good varieties, b) soil fertility, c) sunlight, d) irrigation, e) disease control, f) insect control, and g) a good on site manager.

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Let's now look at these requirements in detail:

Topography. Topography is important because of soil erosion and air drainage. Past land use, growing row crops or winter cover crops has resulted in the loss of most of the top soil on hilly land. Pecan trees will not grow well on eroded hilly land. If the topography is too level, poor air drainage will result.

Soils and Drainage. Soils and drainage must be good. Experience has shown that pecans require deep, well drained soils for good tree growth. Air drainage is also important because scab control is more difficult in areas where the humidity is higher due to poor air drainage. Fortunately, the men who planted pecans in Southwest Georgia 70 years ago did in most cases select good soils for pecans.

Growing Season. Pecans require a long growing season with at least 240 frost-free days. There are areas in this country where late spring frosts and early fall freezes damage the pecan crop. Late spring frosts do occasionally happen in Southwest Georgia, but the occurrence is so seldom that the risk is acceptable.

Water Supply. A good water supply is critical. Irrigation is essential for the best pecan production. Growing pecans without irrigation is very risky. Southwest Georgia has an annual rainfall of about 50 inches with 30 inches during the growing season. My experience shows that 20 to 30 inches of water from sprinkler irrigation is needed for the best tree growth and nut production. This means that a total of 50 to 60 inches of water is needed for good pecan production.

Good Varieties. Good varieties of pecans must be present for successful production. There have been several hundred varieties of pecans. Most varieties have not been satisfactory. I consider Desirable and Stuart to be the best varieties in my area. Other varieties that are acceptable in our mixed variety orchards are Schley, Pabst, VanDeman, Cape Fear and Sumner. Varieties such as Mobile, Frostcher, Teche, Success, Curtis, Moore, Moneymaker, Nelson, Waukenna and seedlings are not suitable, and I remove these varieties and replace them with Desirable or Stuart. None of the Indian varieties have proven to be suitable at this time. In several orchards, Wichita trees are being cut down or top worked. Some old orchards have been abandoned because of bad varieties.

Soil Fertility. Pecan trees respond well to fertilizer and it is quite obvious if you look at trees that have been abandoned.

Annual soil and leaf tests must be made in order to monitor the fertilizer program. These tests along with good records on fertilizer applications show what the fertility status of the orchard is and whether the levels of individual fertilizer elements are remaining in the desired range.

My present fertilizer program splits nitrogen into three applications. These applications are about April 1, May 1, and June 1. A total of 200 units of nitrogen is usually applied. Phosphorus and potassium are split into two applications that are applied halfway between the nitrogen applications. Boron is applied with the phosphorus and potassium. Zinc is applied with the fungicide sprays. Zinc sulfate and potassium nitrate are used.

Sunlight. Sunlight is extremely important because pecans fruit on the end of terminals. This means that most of the nuts are on the outside of the tree. Pecans are quite sensitive to shade and limbs die if excessively shaded. When limbs are lost, nut production is reduced. Many orchards in the Albany area are too crowded and nut production is low. Sunlight can be managed by tree spacing, pruning and tree removal. Most of the young orchards in my area were planted 48 trees per acre, and are already crowded at 15 to 20 years of age. The old orchards were usually planted 20 trees per acre and are crowded unless trees have been removed.

The first step in getting more sunlight is to establish permanent and temporary rows on the diagonal. As needed, trees on the temporary rows can be pruned or removed so that the limbs on the permanent trees are not shaded. Eventually all the trees on the temporary rows may have to be removed leaving one half of the original tree stand. All the sunlight on an acre should be used. To do this, trees should be planted in any skips on the permanent rows.

Lack of sunlight due to cloudy, rainy weather in August and September can cause poor quality nuts. This happened in 1989. The quality was worse where the trees were too crowded.

Irrigation. Irrigation has proven to be very worthwhile in Southwest Georgia. About 60% of the orchards are irrigated using primarily drip or solid set sprinklers.

Drip irrigation is the most widely used because of the lower cost to install the system. In some cases drip must be used because there is not enough water available for sprinklers.

Drip irrigation is much better than no irrigation. However, these systems do not apply enough water for the best tree growth and production. Maintenance of drip is difficult and many growers do not keep their systems fully operational which results in some trees receiving very little water.

Solid set sprinklers are the best systems for pecans in Southwest Georgia. When the system is properly operated, tree growth is good which results in much better nut production. Maintenance of sprinklers is much easier than for drip.

There has been very little research on water needs of pecans in the southwestern pecan area and this is especially true for sprinkler irrigation. One research project applied one and one-half inches of water in six hours. Much of the water just ended up in ponds in the low areas of the orchard.

Since 1978 I have been using a plan I developed for sprinkler irrigation of pecans. In the orchard where this plan was started, the five year average yield (1973-1978) was 688 pounds per acre without irrigation. The average yield for the last nine years (1980-1989) was 1,418 pounds per acre. Some blocks in the orchard have produced as much as 2,497 pounds per acre. The highest year, 1987, had a yield of 1,812 pounds per acre on 531 acres. The lowest year, 1989, had a yield of 839 pounds per acre. No doubt some of the yield increase was due to other management practices. However, I believe at least 75% of the yield increase was due to adequate moisture from sprinkler irrigation. In addition to good yields adequate moisture has resulted in good quality and good nut size. The average for the past four years was 49.9% kernel and a count per pound of 55 which is very good for a mixed variety orchard.

My irrigation plan is based on the use of an evaporation pan and a good rain gauge. I have assumed that pecans use as much as 0.30 inches of water per day. The plan is designed to keep available moisture in the top 24 inches of the soil at all times. A bulldozer was used to dig holes so that the location of feeder roots could be determined. Most of the feeder roots were in the top 12 to 15 inches. Rainfall of less than 0.30 inches is not counted in figuring irrigation needs. From 75% to 90% of pan evaporation is

replaced with each irrigation. The most water is applied in late August and September when the trees use more water during nut filling.

This method of irrigation gives vigorous growth in the top of the trees. New growth of 10 to 12 feet in the top is common. This vigorous growth results in good nut crops.

Irrigation is in use from April 15th until a killing frost in November. I consider irrigation so important that, if necessary, harvest is stopped to permit needed irrigation. The cost for pumping water to irrigate pecans has been $50 to $70 per acre per year, and the total cost to irrigate has been about $100 per acre.

Disease Control. Diseases such as scab, downy spot, zonate leafspot and other foliar diseases can be controlled if present fungicide recommendations are followed and the sprayer is operated to give good coverage.

Insect Control. Insect control is difficult due to the ability of insects to become tolerant or resistant to the insecticides in use. The removal from the market of effective insecticides by Federal Agencies has made insect control more difficult. A good scouting program must be carried out along with good spray coverage to achieve good insect control. Beneficial insects are encouraged. Selection of insecticides always consider the effect on beneficial insects.

My orchard manager and I do some insect scouting. However, it is easy to get too busy and not check on a timely basis. Therefore, I use an insect scout who makes weekly inspections of the orchard. I also want the second opinion from the scout who is well informed on insect problems in the area.

Darrell Sparks is employed as consultant. He helps insure that the planned program is the best. This is another instance where a second opinion is valuable.

A Good Site Manager. The best of plans will not result in profitable orchard management unless there is a good on site manager in charge of the orchard who will carry out the management plans in a timely manner. Being on time is very important. Of course, there must be enough machinery and sprayers in good operating condition.

I train and educate my on site managers so that they know and understand as much as possible about pecans. A manager can and will do a much better job when he knows and understands what needs to be done.

Summary. In summary, all the basic requirements must be in place to achieve good pecan production. The difference between Dougherty County's yield of 850 pounds per acre and the yield of 1,418 pounds per acre on one of the farms that I manage shows that good pecan orchard management pays.

ECONOMICS AND MARKETING

James Swink[1]

The American Pecan fortunately enjoys a very fine reputation and is the most versatile American tree nut available to the various ingredient industries in the United States. Pecans do very well on the retail shelf on a seasonal basis and are very popular in mail order departments. Properly grown, processed and marketed, the American pecan industry will enjoy a long and prosperous life.

From a shelling and processing point of view, pecans are an expensive nut to process. Unlike almonds, pecans must be individually cracked. Extensive electronic color and shell separating equipment, sizing, floating, and dryers are used to further perfect the finished product. Finally, and extremely important, proper freezer storage is utilized to retain constant color and flavor of the pecan kernels. The shelling industry continues to become more specialized and automated in efforts to control processing cost and produce a better finished product. One area of tremendous growth potential is with the national ingredient baking, dairy and confectionery companies. Not only is there large volume involved, but very high exposure of pecans as an ingredient. These companies have great marketing clout and the pecan could enter more households through these channels. This added exposure will ultimately increase pecan recognition, desirability and consumption. In order to supply these national accounts, many things must be in place. It behooves the grower to produce the best raw material possible and the sheller to process the product efficiently and effectively. The almond and walnut industries, in particular companies like Blue Diamond Almond and Diamond Walnut, have very modern and sophisticated processing plants and marketing programs. They are very effective in providing national accounts with consistent finished material, both from a color and a shell or foreign material standpoint. Their plants are very clean and can withstand the scrutiny from quality control teams from the various national end users. Within the past few years, the pecan shelling companies have brought the finished goods standards drastically upwards. Since 1985, our company alone has invested over $8,000,000.00 in new plants and equipment to better process the pecan crop and compete head-to-head with the large walnut and almond nut companies for the attention of the national ingredient users. Our three processing plants are all equipped with the newest Quantz cracking system. We have the latest in visual electronic color sorting and the newest technology available for shell separation, the ESM infrared light electronic sorters. This process allows us to offer virtually zero-shell control in our finished product. All of our facilities have on sight freezer storage, in-house micro and quality control labs. Our home plant in Florence, South Carolina has implemented the Statistical Process Control program that is now being required by some national accounts to insure a consistent finished product. We too can withstand the scrutiny of the strictest quality assurance inspection and compete equally with the other large nut manufacturers. The pecan shelling industry has evolved into a very specialized and competitive industry.

Processing facilities are very costly to build, equip and maintain. However, the largest cost in the shelling industries is the financing of the crop. It takes a very large cash reserve or line of credit to buy the crop during the harvest season and hold it for shelling and delivery during an entire 12-month crop year or longer. Normally, there is only one turnover of money per year for a pecan sheller marketing in commercial channels. With the industry operating on very close margins, and the federal financial regulators tightening up various ratios, lines of credit are coming under more pressure. It could certainly be advantageous for the growers and shellers to become creative in a joint arrangement in this area. We for one, would certainly entertain such discussions.

From a marketing viewpoint, one would think it would be an easy task to market America's most popular nut. It is very high in nutritional value and very flavorful. The marketing of this nut is done primarily by individual shelling companies consisting of in-house sales personnel and a network of broker representatives throughout the United States. Like many other ingredient or retail food items, the customer is looking for a consistently good product, competitively priced and serviced on a timely basis. The shelling

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industry consists of two segments, the large commercial sheller and the small specialty processor. Some organizations have a balance of the two. In the case of the commercial sheller's marketing, emphasis is placed on existing business and the creation of new applications for pecans. Our company places significant emphasis on working with the research and development departments of the various national and international food companies. Whether its with creating new formulas for conventional products such as baking items, confectionery items or ice cream products, or developing new applications for breads, rice, cereals, cheese, yogurts or the snacking industry, a constant effort is made to increase overall consumption. Extensive travel is involved in promoting the pecan at research and buying headquarters throughout the United States. We participate and exhibit in approximately five food trade shows each year, both domestically and internationally. Substantial efforts are being made on the international scene and after intense marketing efforts, our company is now realizing significant growth in foreign markets for the pecan. I will not expound on this as I understand this area will be addressed later in our meetings.

With the crop sizes being up since 1981, product development and overall consumption has been at all time highs. The 1989 crop was off in size, but the large carry-in to the '89 crop helped maintain the strong supply levels. To date, cold storage buildings are approximately 35% less than last year. Finished good prices are up approximately 45% over last year and consumption remains strong. I believe the stage is set for a continuation of firmness on into the new crop.

The world almond supply is expecting to surpass 1 billion pounds and the walnut crop in excess of 800 million pounds, we should be bracing for more competition from these nuts. Almond kernels are currently being sold in the $1.20 range with walnuts in the $1.60 range. At some point, with pecans in the $2.85 range, consumption could be affected. I believe we can maintain strong consumption and demand on high priced kernel cost for this year. However if the 1990 crop turns up short and prices are high again, consumption and development will be affected. A problem could develop if we come back very strong in 1991. There could be an oversupply and prices could overreact downwards. These scenarios are difficult from a marketing standpoint. With the exception of last year's crop, the pecan total supplies have been fairly consistent. One blip in an 8-year cycle should not hurt consumption or discourage new product development for pecans.

Some of the western acreage has stabilized the supply situation in that they tend to be more consistent in yield. But two consecutive short crops could change the progress of pecan marketing with adverse consequences for all of the industry for several years. Broad swings in prices discourage serious new product development and particularly export efforts.

There has been extensive study and development in the snack food areas. There are many coatings and value added processes that are being offered today. In our particular case for an example, we utilize our product research and development department to create a value added product with pecans. This product is tested internally for consumer acceptance. Upon an accepted product, we will display and sample the product in one of our three retail outlets. If the product is received well, we will then add it to our mail order catalogues. If it continues to be well received, we will offer the item to the retail and snacking industries. Ultimately, our goal is to offer for distribution to the industrial industries, adding processing equipment to our existing specialty sales kitchen and processing areas. Every phase of marketing efforts helps to expose the pecan to more consumers.

The Pecan Marketing Agreement that will be initiated sometime in 1991 is most encouraging from a marketing viewpoint. Never before has the pecan been promoted to the general public as it soon will be. We are extremely optimistic to national and international exposure for the pecan and its ultimate increased demand.

Many people believe the industry is going through a serious crises and it is. Both the growing and shelling segments of the industry are under capitalized and are in an unhealthy financial environment. The growers as well as the shellers are not receiving proper returns for their investments. With inadequate returns, the growers are not able to properly maintain their orchards to insure the best quality yields. With this general deterioration, the industry is struggling with the inconsistent supplies and quality. We as an industry are fortunate in that pecans are primarily produced in the U.S. Think of the difficulties that we would have if Europe, China or South America were producing pecans in large quantities. Not only would we have to organize the American Industry, but contend with the world market. The growers and shellers of the U.S. should make every effort possible to organize our efforts and resources to develop a healthy environment. The industry should encourage

product development and growth both domestically and internationally rather than shellers increasing sales by cutting prices and taking business from other shellers.

Since 1986, the shelling industry has been under an intense price war, and as a result, nine shelling companies have closed. If this trend continues and the industry is reduced to one primary buyer, then the growing industry will be at the mercy of one company who can dictate both what the grower will receive and what the end user will pay. It has been estimated that the crash of the pecan market during the 1986-87 crop year caused the shelling industry to lose between 60 and 80 million dollars in retained earnings and in the reduction of bank lines of credit; in other words, total cash used by the shellers to buy the crop from the growers for processing and marketing. This put some shellers out of business and substantially weakened most of the others. If this trend continues, it is conceivable that the shellers will not have enough money available to them to buy the entire crop from growers. At that point, growers would have to find a way to help in financing their crop to the end user, and to wait in effect for an average of up to a year or more to be compensated for a given crop.

The overall consumption for pecans has been very encouraging. Last September the industry carried 107 million pounds into the 1989 crop. The final crop figures for the '89 crop was recently reported by USDA to be 234 million pounds. Adding another 16 million pounds from the non-reporting states and approximately 25 million imported from Mexico gave us a total supply of 382 million pounds. Based on current cold storage holdings and what we anticipate moving between now and September 30, we should have a carry in position of approximately 55 million pounds. This would put pecan consumption at 327 million pounds, the highest on record! This year's crop was moved at comfortable levels.

In summary, I would like to say that growers and shellers are both heavily committed from a financial position to the success of pecan. As a sheller, we fully realize the importance of a healthy grower base. Without this base, the industry has no future. The shellers must support this fact and the two integral parts of the industry must continue working together exchanging accurate and timely information and understanding one another's problems. I believe consideration should be given to creating a grower/sheller organization to enhance and promote these two segments of the pecan industry. By so doing we can have an adequate and a healthy exchange of information as to what is affecting our industry for good or for bad, and to react accordingly in our own best interest. The growers must commit to improved quality in the orchards and stability in crop size, and the shellers must commit to improving processing technology and consistent and creative marketing plans.

We have at our disposal a nut that no one else in the world has -- a nut that has tremendous consumer appeal and tremendous potential. Together we decide the pecan's future and our future.

KEYS TO PROFITABILITY FOR COMMERCIAL PECANS

George Ray McEachern[1]

ABSTRACT

Low alternate yields of poor grade pecans and numerous management inadequacies resulted in general decline in profitability of pecans during the 1980's. The key to the future profits depends on increased yields and quality by obtaining optimum root absorption, light utilization and nut grading prior to first sale.

INTRODUCTION

Commercial pecan producers have had difficulty in obtaining profits in the 1980's because of alternate bearing, failure to grade nuts prior to sale, the industries inability to estimate the crop size prior to harvest, high interest rates on money used to purchase the crop, loss in medium sized shelling companies, a wide range in the types of pecans produced, a high volume of low grade pecans during high yield seasons, low wholesale prices for peanuts, almonds and walnuts, competition of high quality pecans from Mexico, low advertising strength, a large number of oversized poorly financed orchards, insufficient irrigation, inappropriate orchard soil, failure to destroy non-productive orchards, and limited knowledge of pecan culture.

Despite these limitations or challenges, the future for pecan profitability is greater today than ever before. Regular production of over 1,200 pounds per acre of top quality pecans for over 10 years in numerous orchards illustrates the potential exists. Some orchards have averaged up to 2,000 pounds and a rare few have produced even more per acre for a continuous period of time.

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To obtain profitable production levels, producers are going to have to produce both high yields and high quality fruit for a number of consecutive years. The question is, how can this be accomplished? Major changes have occurred from 1970 to 1990 in the pecan industry. Fungicides, insecticides, drip irrigation, small tree trunk shakers, pull type PTO harvesters, small portable cleaners, and other industry changes have been introduced and widely accepted throughout the industry. Cultural practices such as fertilization, weed control, integrated pest management, varieties, central leader tree training, intensive orchard establishment and other cultural practices have been developed and become positive practices throughout much of the industry. Unfortunately, some negative practices which were never proven to be profitable were introduced and adopted by many growers. These include ultra high density spacing, mechanical pruning, precious varieties and scab susceptible varieties. In addition, harvesting, handling, shelling, marketing and advertising can be improved to assist pecan growers in obtaining profits.

The three major practices or concepts discussed here need to be researched and developed into functional cultural practices to assist growers of the future realize sufficient profits and continuous production. Functional solutions are available for most of the other management challenges facing the industry.

WATER ABSORPTION

Pecans require a great volume of water daily. All of the mineral elements essential for leaf growth and fruit development are dissolved in the soil water and depend on absorption. The fact that the soil contains water and minerals does not mean the roots will absorb them, in many cases it is fair to assume they will not be absorbed.

Soil water management for maximum absorption will be the key in the future of pecans. Absorption is far more complex than most scientists realize and the management practices needed will be both technical and intensive. Mathematical models are currently available for determining the volume of water required by various size trees at any climactic site in the industry. A second factor is how much water will the soil hold. This depends on soil depth, texture, structure, and other factors. It will be important to determine the speed and deep the water enters the soil. There is also the question of what percent of the water holding capacity is optimum. The total orchard floor needs to be irrigated.

The soil air, oxygen or aeration level is a major factor in the soil water absorption process. As a grower attempts to determine how to irrigate, it will be important to know how deep soil oxygen is present in the soil. No oxygen is equal to no absorption. Essentially all water and minerals are absorbed from the top 30 inches of soil because this is where the soil oxygen is present. The soil oxygen level is determined by soil depth, texture, structure, water holding capacity, and most importantly, surface and internal water drainage.

Low water absorption can be the direct result of shallow soil, poor structured clay soil, no irrigation, tree crowding, old tree age, poor drainage and other factors.

The key to regular pecan production and quality in the future is knowing the water absorption potential of the orchard soil and the development of a water management system which optimizes water absorption on a daily basis.

LIGHT UTILIZATION

As roots absorb water, the pecan leaves must absorb light to convert carbon dioxide and water into sugar and subsequently all the food the pecan tree uses to grow and bear regular crops of quality pecans. Without photosynthesis, the tree will not produce effectively.

Shade is the major limitation to photosynthesis. Tree crowding cannot be tolerated because it shades the lower canopy. Sunlight should contact the lowest limbs as well as it does the very top. To prevent shading, trees need to be thinned out as the lower limbs touch. There has not been a successful tree pruning system, mechanical or hand, for use on commercial pecans. Tree removal is the only functional system of maintaining a pecan orchard at its full production potential. Trees should be spaced as close as possible at planting to increase early tree production; however, as soon as lower limbs touch shading of the lower canopy will occur and trees will need to be removed. This can occur as early as the ninth year on ideal sites where intensive management has been given.

The consequences of shading and crowding is recognized first as poorly filled nuts, followed by total failure to bear. It is not fair to assume economical yields can occur in crowded orchards because it will not. By thinning trees, yields are reduced the first two years after thinning, but more importantly, yields will continue. This has been proven time and again over the last 20 years in both small and large orchards.

No management practice can compensate for shade from crowding. Stated in its simplest form, when shading occurs, no photosynthesis occurs and growth stops.

Prior to planting a pecan orchard, growers should devote a great deal of effort to planning the spacing and the sequential tree removal as crowding occurs.

Thinning is the single most difficult cultural practice a grower must accomplish however, it must be done.

GRADING PECANS PRIOR TO SALE

It has been said that pecan marketing is the last legal totally free enterprise in the United States. Unfortunately, it is a true statement. Growers do not have or do they create any economic leverage prior to making a sale. The system is simple, here are my pecans, pay me what you can.

As growers market their pecans they should have and use a system to grade their pecans to determine their value. There is a very wide range in kernel quality within the pecan industry. As a general rule, young orchards on good sites which are well managed tend to produce higher quality pecans, while there are numerous old orchards on poor sites which are not well managed which produce poor quality pecans.

There is not a universally accepted method of measuring and expressing the kernel or market quality of inshell pecans as they leave the orchard for sale. Consequently, the grower typically waits until the buyer or sheller determines a value for the pecans. This system of value determination allows the buyer a degree of economic protection from non-edible pecans, rapid price changes and other factors which commonly alter the price or value of pecans.

To determine the value of pecans, it is essential that a grower and buyer know the percent edible kernel of the pecans to be sold. Buyers and shellers cannot afford to pay for damaged or flawed pecans.

The percent edible kernel could be determined by removing all of the non-edible kernels. Before measuring percent edible kernel, all flaws such as cracked shell, adhering shuck, stink bug, embryo rot, weevil, fuzz, mold, wafer, and others need to be removed from the sample to obtain a true percent edible kernel.

Kernel color is very important in determining the value of a sample. The lighter the kernel color, the higher the value of the sample, when all other factors are equal. The colors could be designated as cream, golden, light brown, brown and black. cream and golden could be classified as fancy, light brown as choice, brown as standard and black as damaged.

Nut size can also influence sample value. The larger the size, the higher the value of the sample when the edible kernel and color are the same.

A new system, if it is to be developed, needs to be simple, easy to understand and within the capability of most growers.

INSECTS AND PECAN PRODUCTION

Jim Dutcher[1]

The complex of insect pests on pecan causes considerable damage to the tree and its foliage and nuts each season. Foliar insect damage accelerates leaf drop in the fall leading to reduced reblooming of both pistillate and staminate flowers the following spring. Nut feeding insects cause direct yield losses each season. In addition, before harvest the tree naturally loses 23-45% of the pistillate flowers and fruit from natural abortion (Sparks and Madden 1984). Short term (less than four years) effects of aphid control have been reported (Dutcher et al. 1984, Dutcher 1985, Wood and Tedders 1986). We report the results of research on the long term impact of pecan aphid control with aldicarb compared to control of aphids with foliar insecticide applications. The impact of pecan weevil damage on pecan production was gleaned from the literature (Boethel et al. 1976a, 1976b, Criswell et al. 1975, Dutcher and Payne 1981, Hall et al. 1979, Hall and Eikenbary 1983, Harris 1976, Raney et al. 1970, Tedders and Osburn 1971).

Method and Materials

The impact of aphid control was determined over a nine year period at an experimental, drip-irrigated, pecan orchard in Sumter Co., Georgia. The site was a mature orchard with sixty-year-old trees planted on a 18 x 18 m spacing. The orchard floor was a mowed sod with a herbicided strip running down the tree row, 2 m on either side of each tree. The trees were divided into three groups based on the type of aphid control applied during the season: 1) untreated trees; 2) trees treated with foliar applications of esfenvalerate (@ 0.11 kg ai/ha), endosulfan (@ 0.82 kg ai/ha), cypermethrin (@ 0.11 kg ai/ha) or bifenthrin (@ 0.082 kg ai/ha) for pecan aphid control; and 3) trees treated with aldicarb as an emitter adjacent application at 2.6 kg ai/ha and applied on July 15 each year (Dutcher and Harrison 1984). Treatments 2 and 3 were sprayed with carbaryl each season for pecan weevil control by the guidelines of the University of Georgia Cooperative Extension Service (Ellis and Bertrand 1979). Treatments were not applied to the same plots for the entire duration of the study as control trees would have gone into a nonbearing mode for several years. Rather, plots were rotated between treatments at the beginning of each season so that plots were not in the control group or the aldicarb treated group for consecutive seasons. The untreated trees often suffered high infestations of nut pests and these losses were difficult to separate from losses caused by a lack of aphid control. Therefore, the infestation information collected in the untreated trees was used to show the presence and relative size of the pest infestations and overall production between aldicarb and foliar insecticide treated trees were compared. Yield was measured at harvest in the late fall during each season from 1981-1989.

Results

Trees treated with aldicarb had higher production than trees treated with foliar insecticides alone in all years except for 1987 when the Stuart trees with foliar applied aphid controls outproduced the trees with aldicarb treatments. Overall production increases by aldicarb applications were 32% for Schley (Fig. 1) and 22% for Stuart (Fig. 2).

Pecan weevil damage and the density of the emerging adult population have been measured in Oklahoma (Eikenbary et al. 1977) where two carbaryl treated populations of 25 and 15 weevils/trap-year, respectively, had 2.4% and 0.6% damage with average yields of 205 and 170 lbs of pecans per tree. In the same study, weevil populations of 88, 197 and 400 weevils/tree (estimated by knockdown sprays), respectively, caused 57, 60 and 90% damage to average crops of 45, 40 and 40 lbs/tree. In Georgia, Payne et al. (1985) found that closed cone cage trap catches of 8, 7, 7, and 3.5 weevils/trap-year corresponded to damage ratings of 23, 61, 30, and 12% damage, respectively, for the 1978, 1979, 1980, and 1981 seasons, where, 1979 had a relatively low yield.

Dutcher and Payne (1981) found that an average cone cage trap catch of 23 weevils/trap-year corresponded to 40% damage with an average yield of 120 lbs/tree. Dutcher and Payne (1988) in an insecticide evaluation where the treatments did not control the pecan weevil, found that, in the treatments and the untreated control, an average

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weevil emergence density of 1.25 weevils/trap-year corresponded to 58% damage with a yield of 28 lbs/tree. These results indicate that pecan weevil damage is only marginally related to trap catch within an orchard. The percent damage tended to be higher in the plots with a low yield than in plots with a high yield. Pecan weevil damage is highly variable between trees within the same orchard and year. Trap catch beneath a tree is not usually related to the damage cause in the same tree (Dutcher and Payne 1981). The range of percent weevil damage in untreated trees in orchards with a pecan weevil infestation ranges from 0.5 to 90%.

Discussion

Pecan production losses caused by poor aphid control are not readily apparent during the first year of a poor control program. The reductions occur after two and three seasons of poor control. The mechanism for these yield reductions is a decrease in reblooming of pistillate flowers in the spring following a fall with reduced foliage retention caused by aphid damage. The reblooming reduction response occurs: As a step function to severe and not moderate or low aphid damage after the first year; as a linear response after the second year; and as a step function to severe and moderate and not low aphid damage after the third year (Dutcher et al. 1984, Dutcher and Harrison 1984, Dutcher 1985). Fortunately, the trees will respond with increased reblooming after one season of excellent aphid control, without regard to their previous amount of aphid damage (Dutcher 1985, unpublished annual research report).

The damage potential of the pecan weevil is high and preventative pecan weevil control requires preventative treatment with carbaryl. Oviposition success is related to nut phenology (Calcote 1975, Criswell et al. 1975, Harris 1976a, 1976b, Dutcher and Payne 1981). Emergence of adults is associated edaphic control variables (Harris and Ring 1980, Dutcher and Payne 1981, Alverson et al. 1984). In Oklahoma, losses from premature nut drop caused by pecan weevil feeding before the kernels are susceptible to oviposition can account for 23-47% of the pecan weevil damage in orchards were the trees were sprayed to prevent successful oviposition (Hall et al. 1981). The variables controlling pecan weevil damage have not been measured in enough field experiments to produce a model of this important bionomic event with any regional applicability. Yield of the pecan under the best available conditions is irregular and variability between trees in any year (Worley et al. 1983) making it very difficult to determine yield differences in field experiments.

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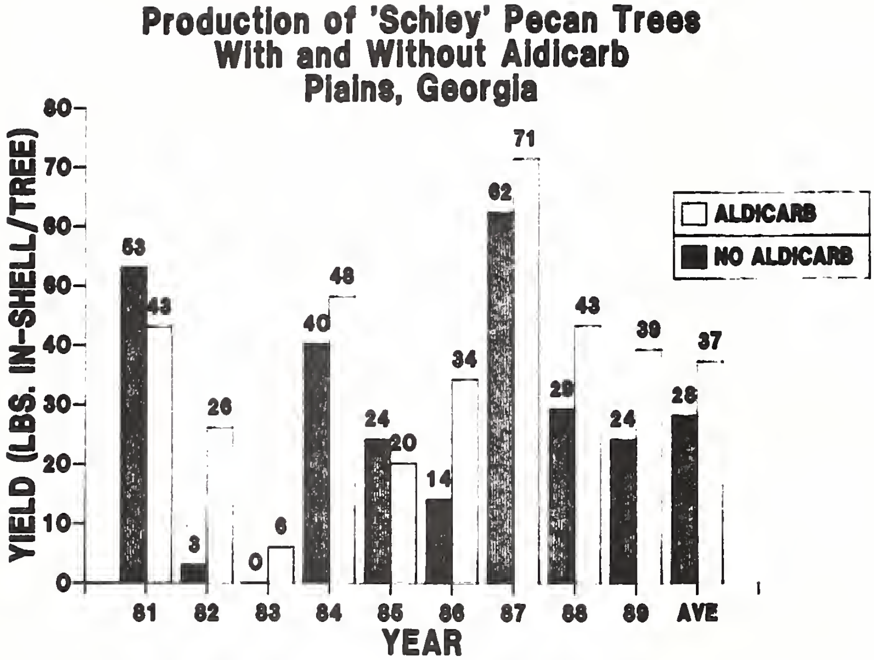

Figure 1. Production of 'Schley' pecan trees with and without aldicarb, Plains, Georgia.

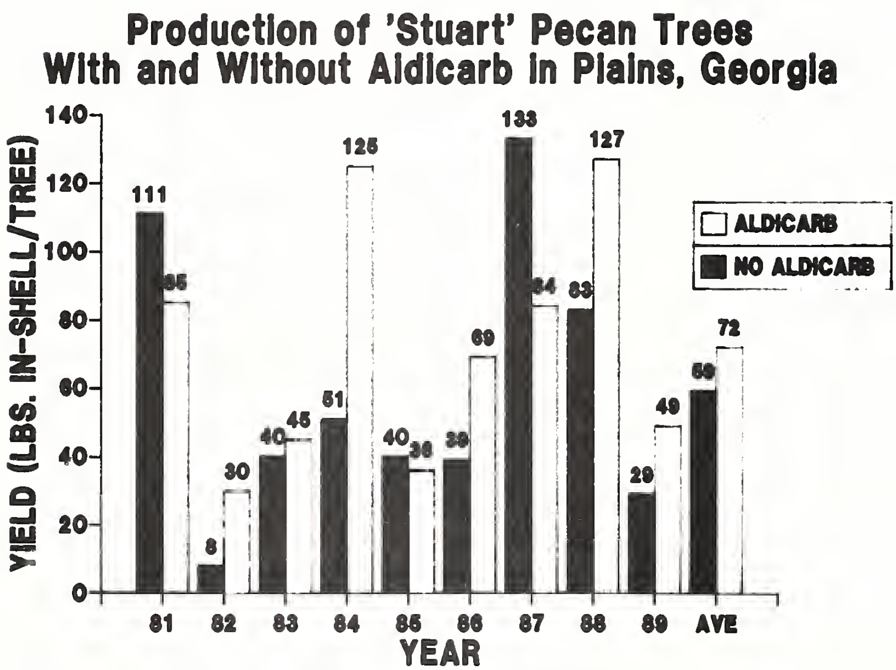

Figure 2. Production of 'Stuart' pecan trees with and without aldicarb, Plains, Georgia.

PESTICIDES AND BENEFICIAL INSECTS: APPLICATION OF CURRENT KNOWLEDGE AND FUTURE NEEDS

Russell F. Mizell, III[1]

Integration of beneficial arthropods and chemical pesticides into a pest management program has been discussed often but received little application until recently. The main reason for this is that chemical pesticides were cheap, available and effective and most are harmful to beneficials. Little information on the effect of pesticides on specific species and stages of beneficials in pecan were available, therefore an investigation was initiated. This paper discusses the results of the study, some of its implications with respect to integration of pesticides and beneficial arthropods into a pecan pest management program, and related issues.

Management of arthropod and disease pests of pecan continues to be a major problem for the pecan grower and a primary subject of research. Despite the availability and use of (some may say because of) chemical pesticides, losses from pests such as pecan scab, yellow and black pecan aphids, pecan weevil, hickory shuckworm and nut casebearer remain very high in most pecan growing areas. Control of foliar feeding or "indirect" pests such as diseases, aphids, mites, and miscellaneous leaf feeders, is extremely important because the leaves, through photosynthesis, produce the energy for the tree. Therefore, it is important to maintain high quality foliage from budbreak to frost (Tedders 1978, Tedders and Thompson 1981, Wood and Tedders 1982, Tedders et al. 1982, Dutcher 1985, Tedders and Wood 1985, Wood et al. 1985, Wood et al. 1987).

Because pecan is a long-season crop with some species of pests occurring at most times during the seven month growing season, successful pest management requires consistent monitoring of pest populations and often difficult decision-making by the grower. Decisions to apply pesticides for early season pests may affect outbreaks of other pests in late season. Pesticides vary in efficacy, residual duration, and in their impact on non-target organisms such as beneficial insects and mites that may be important in the natural control of both primary and secondary pests. Therefore, the selection and application of specific chemicals may not only affect short-term control of the target pests, but also may induce a resurgence of the target pest at higher levels (aphids for example) or induce outbreaks of secondary pests, e.g., scorch mites. Chemical control of pecan aphids has also resulted in development of resistance to pesticides by this pest (Dutcher and Htay 1985).

From the pesticide industry's perspective, pecan is a "minor use" crop with respect to the total amount of pesticides used by pecan growers. Therefore, chemical companies in their present form will not be registering a lot of new pesticides with EPA for use on pecan. Additionally, some of the older pesticides currently registered for pecan are being reviewed by EPA and either by force or choice will be withdrawn from the market by chemical companies. Everyone by now knows what a severe blow the loss of Zolone was to the pecan industry. Our available chemical tools are dwindling and not apt to be replaced in the near term. Clearly, alternative tactics are needed to reduce pesticide use, retain the efficacy of available pesticides, and enhance the impact of beneficials.

The pecan aphid complex is now considered one of the most important pecan pests. Biological control of aphids is receiving much attention and appears promising (Tedders 1983, Liao et al. 1984, Edelson and Estes 1987, Mizell and Schiffhauer 1987b, Bugg and Dutcher 1989) as is discussed by Tedders in this workshop. Many beneficials prey upon pecan aphids and other pests and may be adversely affected by pesticide use (Ball 1981, Dutcher 1983, Dutcher and Payne 1983); however, pesticides cannot be totally eliminated because of the need to control pests other than aphids and limited progress in the implementation of aphid biological control.

One way to conserve beneficials is to use selective pesticides. Integration of chemical and biological control is not new (Ripper et al. 1951, van den Bosch and Stern 1962, Bartlett 1964, Croft and Strickler 1983), however, the required data on the toxicity of pesticides to natural enemies were not available for pecan or from other crops. We recently conducted a study of the effect of pecan

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pesticides on at least one lifestage of five important natural enemies of pecan aphids (Mizell and Schiffhauer 1990).

MATERIALS AND METHODS

We used established methods in laboratory bioassays to develop the data (Mizell and Schiffhauer 1990). We tested the following species and life stages of beneficials: Egg, larva, and adult stages of the lacewing, *Chrysoperla rufilabris* (Burmeister), adults of the lady beetles, *Hippodamia convergens* (Guerin-Meneville), *Cycloneda sanguinea* (L.), *Olla nigrum* (Say), and pupae of the parasite, *Aphelinus perpallidus* Gahan. All tests were compared to untreated controls and all insects tested were collected from pecan orchards, in areas adjacent to pecan orchards or were reared from insects originally collected from pecan orchards in Georgia or Florida. All chemicals were tested at the 0.5X and 1X rate suggested on the label for pecan. When a range of rates were suggested we used the median value as the 1X rate.

RESULTS AND DISCUSSION

C. rufilabris. Mortality to eggs was less than 50% from the fungicides Du-ter, Benlate, and Cyprex, the acaricides Kelthane and Vendex, and the insecticides Cygon, Systox, Malathion, Zolone, Thiodan, Guthion, Lindane, and Ethion (Table 1). The fungicides (except for Du-ter) the acaricides, and the insecticides Lindane, Zolone, Thiodan, Pydrin, Cymbush, and Mavrik were not toxic to the larvae. The carbamate insecticides, carbaryl (Sevin and others) and Lannate, were highly toxic to larvae (Table 1). *C. rufilabris* adults and larvae responded to the pesticides similarly with a few exceptions (Table 1). The fungicide Du-ter was not toxic to the adults. The insecticides Thiodan, Zolone, Kelthane and Lindane were toxic to the adults, but not to the larvae. Pyrethroid insecticides were not toxic to either stage.

H. convergens. All pesticides were toxic to adults of this lady beetle with the exception of the fungicides Benlate, Cyprex, Du-ter, the acaricides Vendex and Kelthane and the insecticide Lindane (Table 1).

C. sanguinea. Du-ter caused 60% mortality to adults of this lady beetle (Table 1). Mortality from all other chemicals tested was 70% or higher. *C. sanguinea* and *H. convergens* will not be able to survive in areas where pesticides are applied.

O. v-nigrum. Adults of this lady beetle responded very differently from the other two species tested (Table 1). The fungicides, acaricides, and the insecticides Lindane, Supracide, Malathion, Zolone, and Ethion caused less than 50% mortality. Lower mortality was observed at the 0.5X rate to Cygon, EPN, Parathion and Lorsban, although these compounds caused >50-100% mortality at the 1X rate.

O. v-nigrum overwinters in the pecan orchard (Mizell and Schiffhauer 1987a) and is important during the entire season for aphid control. *O. v-nigrum* shows much promise for use in integrated control programs for pecan aphids. The reduced mortality to *O. v-nigrum* observed at the low (0.5X) rate of Cygon, EPN, Lorsban, and Parathion suggests that this predator may benefit from reduction in spray concentrations in an integrated approach. Because *O. v-nigrum* is especially important in early season against aphids and showed low mortality to Lindane, Lindane may be the chemical of choice for control of pecan phylloxeras.

A. perpallidus. The fungicides, acaricides, and the insecticides Guthion, Zolone, and Lindane caused <50% mortality to the pupae of this parasite (Table 1). Mortality from Lannate and carbaryl was only 57 and 51%, respectively. Only Pydrin, Zolone, Thiodan, Lannate, and Cygon caused significantly less mortality at the 0.5X rate compared to mortality at 1X.

A. perpallidus is the only known native, primary parasite of pecan aphids. The parasite pupae displayed some tolerance (50%) to carbaryl, therefore, surviving parasites may become particularly important in the field against pecan aphids when carbaryl, which kills most of the other natural enemies, is used to control pecan weevil. However, we did not test the toxicity of carbaryl to adult parasites. If carbaryl is highly toxic to the adults, it would negate this potential benefit from the parasite. Carbaryl remains the only pesticide effective against high populations of pecan weevil. This pesticide is particularly toxic to most beneficials as was also shown by Dutcher (1983). Therefore, use of carbaryl will disrupt any biological control program in late season and remains as a significant obstacle to the implementation of biological control of aphids and other pecan pests that may be dependent upon *O. v-nigrum, C. rufilabris, A. perpallidus* or other species of beneficials as yet untested.

Biological control of aphids in the absence of pecan weevil populations appears compatible with control of plant diseases and mites, because all the beneficial species tested were tolerant to the fungicides and acaricides. Integration of natural enemies (particularly *C. rufilabris, O. v-nigrum*, and *A. perpallidus*) with pesticides for management of pecan aphids and other pests has some potential with the use of Thiodan which was generally selective. When specific species of predators (e.g., lacewings) are dominant in the field or released by growers, application of pyrethroids may be feasible to conserve these specific predator populations and suppress aphids without side effects; although, outbreaks of pecan leaf scorch mites may be unavoidable at present. Applications of reduced rates of a few pesticides for which mortality for some predators significantly declined at the 0.5X rate (Lorsban - *O. v-nigrum*) may provide better control of pecan aphids due to the additional mortality from beneficials. These possibilities require further verification in the field.

Pesticides may also be toxic to beneficials through consumption of treated prey. Pesticides may indirectly harm beneficials by starvation or cause their dispersal out of the orchard in response to high mortality to prey populations. We have not investigated these problem, nor have we looked at the effect of sublethal doses on the fecundity or longevity of beneficials. Also, we have not evaluated the effect of pesticides on the immature stages of any of the coccidioides; however, some preliminary work suggests that immature coccidioides are killed by much lower doses than are the adults. These data gaps lead to an even stronger conclusion that the use of pesticides should be avoided whenever possible.

Other approaches to integration of chemical and biological control include alternate row spraying, reduction of rates, tank mixing of pesticides at lower rates, use of granular systemics, chemigation, development of genetically improved, pesticide-resistant strains of beneficials and use of soaps, oils and biorational chemicals. Alternate row spraying has been tested in pecan (HC Ellis, personal communication) for pecan aphids with little success. Tank mixing of pesticides at lower rates, or use of a single pesticide at a reduced rate may have some potential for conserving beneficials, but this is doubtful. Few of the pesticides available for use on pecan showed a reduction in toxicity to beneficials at reduced rates (Table 1). However, this might be a promising approach if a method was available to estimate beneficial populations in the field (I am currently developing a sampling method). We have the granular systemic, aldicarb (Temik), available for use, however, it has problems in some states (Florida and others) with pollution of ground water. We also do not know what impact, if any, the elimination of aphid honeydew by use of aldicarb may have on beneficials normally resident in the orchard. Chemigation also does not appear promising for use in pecan because it has some of the same disadvantages of foliar-applied pesticides in addition to the potential for ground water contamination.

Classical biological control (Debach et al. 1976), the introduction of exotic beneficials that are not inherent members of the pecan ecosystem may have some merit. For example Tedders (1977) introduced *Trioxys pallidus* (Haliday) and *T. complanatus* Quillis-Perez into Georgia from California against pecan aphids. He also released several exotic lady beetles at Byron, Georgia against pecan aphids. These species either did not become established or have not spread to other areas. Other aphid species in other geographical areas of the world that are related to the three native pecan aphids may have beneficials that might also attack the native species. For example the author searched Thailand, Malaysia, and the Philippines in 1988 for parasites of the crapemyrtle aphid, *Sarucallis kahawaluokalani* (Kirkaldy), but was not successful. Any released beneficials will of course be negatively affected by the use of chemical pesticides.

While we may have induced resistance in some beneficials in pecan already (doubtful), development and use of genetically improved beneficials is probably not feasible. Resistance to pesticides by insects usually is accompanied by a cost in energy to the insect which may affect longevity, fecundity, vagility, etc. that places the resistant individual at a disadvantage in the absence of the chemical to which it is resistant. I know of no species of beneficial that has the necessary impact or of a chemical pesticide worthy of repeated use for control of pecan pests that would maintain the advantage of a resistant strain of a beneficial species. However, this judgement may be premature (see Hoy et al. 1990).

Soaps and oils may have limited use in pecan for control of aphids and mites. However, more field tests of the newer, better refined oils are probably needed to determine under what conditions, if any, phytotoxicity may occur. Soaps may also cause mortality to beneficials (Osborne and Petitt 1985, Mizell, unpublished data). *Bacillus thuringiensis*, a bacterial

disease of Lepidoptera, e.g., fall webworm and walnut caterpillar, is labeled for pecan and should be used whenever possible to control these pests.

There are many other beneficial insects and mites we have not been researched that are important in pecan, not only against pecan aphids but also against many other pests. We know very little about their biology, host range, impact or response to chemical pesticides. For example the mirid, *Dereaocoris nebulosus* (Uhler), is one of the most abundant aphid predators in pecan. We know virtually nothing about this species. The same is true of many important species of parasitic Hymenoptera.

It seems clear that pesticides that are toxic to beneficials will have to be used in the near-term by growers. When toxic pesticides are used, it would be useful to know the amount and duration of the toxic residues remaining on the leaf following an application. This would help to better time releases of predators such as lacewings or to help estimate the survivorship of beneficials moving into the orchard. No data collected on pecan is available, however, the information presented in Table 2, based on results garnered from other crops, may serve as a working estimate of the duration of toxic levels of chemical residues.

Pest management of pecan arthropod pests and diseases is in transition between implementation of new non-chemical management tactics and strict reliance on chemical pesticides. In the future, a standard prescription for pest management implementable across the pecan belt will be impossible due to the differences in the species of pest present at economically important levels, the differences in their seasonal abundance, climate and weather patterns, and the myriad of horticulturally-related management practices (Dutcher et al. 1984) that influence the structure surrounding and in the pecan agroecosystems. We still have chemicals available, but use of them is, for the most part, incompatible with biological control. Fungicides are still available to successfully control most pecan diseases and diseases, e.g., pecan scab, must be controlled in the humid Southeast. The acaricide Vendex is still available to control pecan leaf scorch mite. Fungicides and acaricides are usually easy on beneficial insects, however, fungicides may be very detrimental to naturally occurring insect diseases. I did not discuss weed control, but with the present use patterns of herbicides in pecan, herbicides probably do not greatly affect beneficial insects.

In conclusion, the integration of currently available chemical controls and biological control using native beneficial insects will be difficult. Zolone was particularly selective to beneficials and losing it was a severe blow to the industry. Other approaches for control of aphids with beneficials such as development of beneficials resistant to pesticides may have potential but are in the distant future. Further development of a strong knowledge base concerning the biology and behavior of the pests and beneficials under a variety of environmental and management conditions is required before consistent, safe management of pecan pests will become a reality for the pecan grower. This study (Table 3) provides researchers with data to select pesticides which may exclude and retain certain predator species in the field and enable study of their individual roles.

Unfortunately for the industry, new research information often documents a need for greater utilization of pesticides for the control of new pests [see Tedders et al. (1990) for a discussion of the impact of the fire ant, *Solenopsis invicta* Buren, on beneficials]. I can safely predict the future for pecan entomologist as bright and challenging!

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Table 1. Toxicity of pecan pesticides to several pecan aphid predators and a parasite.

	Chemical[a]		*C. rufilabris* Egg	Larva	Adult	*H. convergens* Adult	*O. v-nigrum* Adult	*C. sanquinea* Adult	*A. perpallidus*
Pesticide	Class	Purpose[b]	1x	1x	1x	1x	1x	1x	1x
Methidathion 2E (Supracide)	OP	IN	*[c]	*	*	*	L	*	*
Dimethoate 2E (Cygon)	OP	IN	L	H	H	H	H	H	M
Demeton 6L[e] (Systox)	OP	IN	L	H	H	*	*	*	L
Diazinon AG500[e]	OP	IN	L	H	H	H	H	H	H
Malathion 4.3E	OP	IN	L	H	H	H	L	H	M
EPN 5E[e]	OP	IN	H[d]	H	H	H	H[d]	H	H
Phosalone 3E[e] (Zolone)	OP	IN	L	L	H	H	L	H	L
Endosulfan 2E (Thidan)	CH	IN	L	L	L	M	M[d]	M	L
Parathion 15WP	OP	IN	M[d]	H	H	H	M	H	H
Azinphos-methyl 15WP (Guthion)	OP	IN	L	H	H	H	H	*	L[d]
Chlorpyrifos 4E (Lorsban)	OP	IN	H	H	H	H	M[d]	H	H
Ethion 4E[e]	OP	IN	L	H	H	H	L	*	L[d]
Fenvalerate 2.4E (Pydrin)	PY	IN	H[d]	L	L	H	H	M	H
Cypermethrin 3E (Cymbush)	PY	IN	H	L	L	H	H	*	M
Fluvalinate 2E (Mavrik)	PY	IN	H	L	L	H	H	*	H[d]
Lindane 1.6E	CH	IN	L	L	H	L	L	*	L
Carbaryl 80WP (Sevin)	CA	IN	M[d]	H	H	H	H	H	L
Methomyl 1.6E (Lannate)	CA	IN	*	*	*	H	H	*	L[d]
Dicofol 1.6E (Kelthane)	CH	AC	L	L	H	L[d]	L	*	l
Hexakis 4L (Vendex)	OT	AC	L	L	L	L	L	*	L
Triphenyltin-Hydroxide 4L (Du-ter)	OT	FU	L	L	L	L	L	M[d]	L
Benomyl (50WP (Benlate)	CA	FU	L	L	L	L	L	*	L
Dodine 65WP[e] (Cyprex)	AN	FY	L	L	L	L[d]	L	*	L

[a]OP=organophosphate; PY=pyrethroid; CA=carbamate; OT=organotin; CH=chlorinated hydrocarbon; AN=aliphatic nitrogen.
[b]IN=insecticide; FU=fungicide; AC=acaricide.
[c]*=not tested.
[d]H=>80% mortality; M=mortality $\geq$60<90%; L=mortality<60% from given concentrations in laboratory residue tests.
[e]Not labeled for pecans by EPA.

Table 2. Estimate halflife of dislodgable pesticide residues in the field.

Chemical	Halflife	Crop	Location	Source
Guthion	3-5	Veget.	FL	Andersen et al. 1974
Guthion	46	Citrus	FL	Andersen et al. 1974
Diazinon	1-3	Corn	IA	Harding et al. 1969
Dimethoate	30-50	Fruit	Aust.	Noble 1985
Methyl Parathion	<2	Fruit	FL	Nigg et al. 1979
Malathion	5-8	Citrus	FL	Nigg et al. 1981
Methomyl	<2	Cotton	AZ	Ware et al. 1974
Chlorpyrifos	<1	Cotton	AZ	Ware et al. 1974
Fenvalerate	4	Cotton	AZ	Estesen 1979
Endosulfan	3-6	Cotton	AZ	Estesen 1979
Methidathion	<5	Cirtrus	FL	Thompson et al. 1979
Cypermethrin	3-4	Cotton	AZ	Ware et al. 1983

Table 3. Pecan pesticides used to exclude or conserve specific beneficials or complexes of beneficials and their estimated impact on yellow pecan aphids.

Chemical	Conserve	Exclude	Aphicide
Malathion	*O. v-nigrum*	All others	Fair
Phosalone	All others	*C. rufilabris* *C. sanquinea*	Excellent
Endosulfan	All others	*C. Rufilabris* (adults)	Good
Parathion	None	All	Poor
EPN	None	All	Poor
Azinphos-methyl	*A. perpallidus*	All others	Poor
Chlorpyrifos	*O. v-nigrum*	*All others*	*Poor*
Ethion	*O. v-nigrum* *H. convergens*	*All others*	*Poor*
Fenvalerate	*C. rufilabris*	All others	Fair
Cypermethrin	*C. rufilabris*	All others	Fair
Fluvalinate	*C. rufilabris*	All others	Fair
Carbaryl	*A. perpallidus*	All others	Poor
Dicofol	All others	*C. rufilabris* (adults)	Poor
Lindane	All others	*C. rufilabris*	Fair

PRELIMINARY INVESTIGATIONS ON FIELD IMPLEMENTATION OF THE HICKORY SHUCKWORM SEX PHEROMONE

J.R. McVay[1], G.H. Hedger[2] and R.D. Eikenbary[3]

ABSTRACT

Parameters necessary for field use of the hickory shuckworm sex pheromone were investigated. Studies included: Trap type, vertical distribution, horizonal distribution and cardinal direction. Unanalyzed data indicate traps are most effective when placed 25 to 30 ft. above the orchard floor and midway between the tree center and the dripline. The Pherocon Ic trap was most effective for monitoring purposes of those tested. The effects of trap placement by cardinal direction was uncertain. Studies into the nocturnal flight activity periods and emergence patterns of adult moths from overwintering shuck habitat are also reported.

INTRODUCTION

The hickory shuckworm, *Cydia caryana* (Fitch), is recognized as one of the more damaging arthropod species in commercial pecan orchards. The species is generally distributed throughout the pecan belt from Texas eastward (Osburn et al. 1966).

Historically, controls have consisted of preventative insecticide applications based on nut phenology (Payne and Heaton 1975, Osburn and Tedders 1969). Recently, blacklight traps have been used to help determine spray dates (Strother and McVay 1978). Adult moth size and a large number of non-target insects attracted to the traps make this procedure difficult and time consuming.

Smith et al. (1987) isolated a pheromone from female shuckworm moths that proved attractive to males. With this development, it should become more practical to estimate moth populations. However, many parameters have to be defined before widespread use of the pheromone in IPM systems can be adopted. The studies reported here were designed to answer some of the more pertinent questions.

MATERIALS AND METHODS

Studies were conducted to determine several use parameters for pheromone traps in hickory shuckworm monitoring systems. These included: Trap type effectiveness, vertical distribution (trap height), horizonal distribution (within canopy trap placement) and cardinal direction. Additional studies were conducted to determine nocturnal activity patterns and the emergence patterns of adults from overwintering sites within pecan shucks. All studies were conducted in mature pecan orchards that were predominately composed of trees of the "Stuart" variety. With the exceptions of the emergence pattern study, which required no traps, and the trap type, study which compared three different types, all studies utilized the Pherocon Ic "wing-type" trap. The pheromone utilized was a commercial preparation marketed by Scentry Inc. of Buckeye, AZ.

Trap Type Study

To determine the type of pheromone trap most effective for monitoring shuckworm populations, a 2-year study was conducted in Mobile Co., AL. The chosen orchard was ca. 40 acres in size and consisted of mature trees (65-year-old). Trees were planted on 60 ft. centers and were 60 to 70 ft. in height. For study purposes, 15 trees within the orchard were chosen by the following criteria: (1) Stuart variety; (2) healthy tree with no visible mechanical or natural damage; (3) additional trees of the same variety were located on each directional facing from the data tree (i.e., the data tree was not adjacent to a blank spot or "skip" in the orchard); (4) no data tree was to be located on the orchard perimeter; and (5) data trees were separated by at least 2 non-data trees (180 ft.).

A completely randomized design was used with 15 data trees chosen to be equipped with 1 of 3 types of pheromone traps. Thus, there were 5 replications of each treatment (trap type). Trap types were: (1) Pherocon Ic, the standard "wing" trap used with most pheromone lures and packaged as components of kits offered commercially with the shuckworm pheromone lure; (2) Pherocon Icp, a

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derivative of the Ic trap with notched bottoms which purportedly provide better airflow over the lure (commonly used to monitor the codling moth, *Cydia pomonella* (L.), a relative of the shuckworm); and (3) Pherocon II, a simple diamond-shaped, pull-out trap easier to install and use than the wing-type traps. Traps were installed 30 ft. above the orchard floor in the west facing portion of the canopy. Rope and pulley arrangements facilitated monitoring. In 1989, traps were installed on May 2, and checked at 7-day intervals with all captured insects recorded and removed from the orchard during the visit. Lures and trap bottoms were replaced at 28-day intervals, the study continuing until Oct. 25. In 1990, traps were installed on Mar. 6, and monitored until May 29. Data presented is unanalyzed and expressed as total and percent of total shuckworm males captured for each trap type.

Vertical Distribution (Trap Height) Study

This trial was designed to determine an optimal height at which to suspend pheromone traps for shuckworm population monitoring. A Stuart orchard of ca. 80 acres in Baldwin Co., AL was chosen for study purposes. The 75-year-old trees were 70-90 ft. tall and planted on 60 ft. centers. Data trees were chosen by the same criteria indicated for the trap type study. In 1989, each of 7 trees (replications) was equipped with 2 traps. One trap in each tree was located 15 ft. above the orchard floor and the other at 30 ft. Both were in the West facing portion of the tree canopy. Thirty feet was chosen as the maximum height as it was not felt that the average grower could establish a trap monitoring system any higher.

Traps were placed on Apr. 25, 1889 and monitored weekly until Oct. 30. Again, trap bottoms and lures were replaced at 28-day interval to insure optimum performance. In 1990, an additional 14 trees were randomly selected for inclusion in the test. Seven of these were equipped with a single trap at the 15 ft. height and 7 with single traps at 30 ft. Thus the effects of trap competition in those equipped with 2 traps per tree could be measured. In 1990, traps were installed on Mar. 20 and monitored until Jun. 5.

Horizonal Distribution Study

In order to determine optimal placement horizonally within the pecan tree canopy for pheromone traps, a study was initiated in a Bullock Co., AL orchard. This orchard consisted of ca. 20 acres of mature Stuart trees (75-year-old) about 75 ft. in height and on 60 ft. centers. Criteria for tree selection was identical to the above described studies. Each of 9 trees (replications) was equipped with 3 traps. One trap was located in the center of each tree. The second was placed halfway between the center and the tree's drip-line (15 ft. from the center trap) and the third was at the dripline (30 ft. from the center). All were 30 ft. above the orchard floor and the line of traps extended from the center to the dripline on the West facing of the canopy. Traps were installed on Apr. 26, 1989 and were monitored weekly until Oct. 27. In 1990, traps were installed on Apr. 23 and monitored until Jun. 12. Again, lures and trap bottoms were replaced on a 28-day schedule. Due to equipment problems, it was impossible to redesign the test in 1990 to evaluate trap competition effects.

Cardinal Direction Study

This study was conducted in 1989 and the Spring of 1990 to determine the effects of directional placement on the capture of shuckworm males by pheromone traps. In 1989, the study was located in a 30 acre block of mature Stuart trees (70+-year-old on 60 ft. centers and ca. 80 ft. in height) within a 100 acre orchard in Covington Co., AL. Due to low population levels, the study was moved to another Stuart orchard ca. 20 mi. to the southeast in the same county in 1990. This orchard's trees were the same age, size and on the same spacing as the first. Tree selection criteria was the same as for previously discussed studies. Each of 5 trees (replications) was equipped with 4 traps ca. halfway between the drip-line and tree center, 30 ft. above the orchard floor. In each case, traps were placed to correspond to the cardinal directions (N., S., E., W.). In 1989, placement was accomplished on May 17 and traps monitored until Oct. 2. Placement in 1990 occurred on Mar. 7 and traps were monitored until Jun. 30. Once again, lures and trap bottoms were replaced each 28 days.

Flight Period Study

This study was conducted to determine the nocturnal flight periods of the hickory shuckworm as indicated by pheromone traps. Tedders and Osburn (1970) reported on the nighttime flight patterns of the species based on collection in blacklight traps positioned on the orchard floor. In 1989, traps involved in the Vertical Distribution and Trap Type studies were monitored at hourly intervals during times of peak emergence. Three randomly selected traps were monitored at each location. Dates of monitoring in the trap type orchard were Sept. 9, 25 and Oct. 9, 1989. Dates of monitoring in the vertical

distribution orchard were May 15, Sept. 18 and Oct.19, 1989. In the Spring of 1990, only the sites uses previously in the trap type orchard were monitored on 4 occasions, Mar. 26, Apr. 4, Apr. 18 and May 2. Data were recorded as number of males captured per hour from sunset until sunrise.

Emergence Pattern Study

Calcote and Hyder (1980) and Calcote (1989) reported emergence of adult shuckworms from overwintered larvae in shucks as bimodal. Emergence peaks were found in both spring and summer, with the smaller summer peak coinciding with the time of greatest direct damage attributable to this pest. Accordingly, a study was conducted to determine if the same pattern was detectable in Alabama. Shucks were collected in early Dec., 1988, from known shuckworm infested orchards in Baldwin, Covington and Bullock Counties in Alabama. Shucks were transported to Auburn where those from each orchard were divided evenly among 3 no. 3 galvanized "wash tubs". Each tub had drainage hole drilled in the bottom and was then filled within 2 in. of the top with shucks and covered with screen. The 9 tubs were then placed on supports (3 in. above the soil) in a screen house and checked regularly for emergence until late Feb., 1989. They were then moved, with supports, to an area under the canopy of a large pecan tree. Adult emergence was monitored daily from Mar. 1 until Sept. 29, 1989. Those adults that had emerged were counted, recorded and removed daily.

RESULTS

Data presented are unanalyzed and therefore are given in the simplest terms without claim of significant differences.

Trap Type Study

A total of 422 shuckworm males were taken from all traps in 1989. Of these, 208 (49.3%) were found in Pherocon Ic traps, 136 (32.2%) in Pherocon Icp and 78 (18.5%) in Pherocon II traps. The Pherocon II traps exhibited a tendency to close up over time and probably restricted entrance by the moths. This problem was corrected in 1990 by placement of a wooden brace in the trap to prevent closure. Capture ratios in 1990 reflected slight differences that may have been influenced by this alteration. In that year, a total of 813 males were captured. Pherocon Ic traps accounted for 340 (41.8%), Pherocon Icp for 290 (35.7%) and 183 (22.5%) were found in the Pherocon II type.

During the 2-year study, total captures amounted to 1,235 males: 548 (44.4%) in type Ic, 261 (21.1%) in type II and 426 (34.5%) in type Icp.

Vertical Distribution (Trap Height) Study

During 1989, males captured in the 14 traps of the 7 replications of this study totaled 876. Of this total, 663 or 75.7% were taken from traps located 30 ft. above the orchard floor. The remaining 24.3% (213 moths) were captured at the 15 ft. height. Seasonal averages for the traps were 30.43 at 15 ft. and 94.71 at 30 ft.

In the Spring of 1990, 773 males were captured in the 28 traps installed. The 14 traps installed at 30 ft. accounted for 423 (54.7%) while an equal number located 15 ft. above the orchard floor captured 350 (45.3%). It was interesting that in trees equipped with 2 traps, one at each height, the 7 traps at 30 ft. yielded 191 of 303 captured (63%) while those at 15 ft. accounted for 112 (37%). In trees with single traps, the 7 at 30 ft. captured 232 males while those at 15 ft. yielded 238 (49.4% and 50.6% respectively). This may indicate a great degree of competition among traps where trees were equipped with 2 traps but may also be partially due to the heaviest Spring emergence occurring very early in 1990. The moths, emerging from shucks on the ground, may have been unable to fly very high in the strong prevailing winds of Spring in the Southeast without the benefit of protective foliage on the trees. Over the 2 year study period, 1,649 male moths were captured: 1,079 (65.4%) at 30 ft. and 570 (34,6%) at 15 ft.

Horizonal Distribution Study

Traps yielded 553 male shuckworm adults in 1989. Of this total, 201 (36.4%) came from traps in the tree center, 188 (34%) from those midway between the center and the dripline and 164 (29.6%) from traps at the dripline. Results were similar in 1990. Of a 232 moth total, the tree center traps accounted for 93 (40.1%), while 98 (42.2%) came from midway traps and 41 (17.7%) from those located at the drip-line. Over the 2-year study, 785 adult males were captured: 294 (37.5%), 286 (36.4%) and 205 (26.1%) from the tree center, midway, and dripline traps respectively.

Cardinal Direction Study

The orchard chosen for this study in 1989 proved to have a very low population of hickory shuckworms. Only 41 males were captured throughout the season. Of this small total, 20

(48.8%) were taken from traps on the East facing of the tree, 14 (34.1%) from the North facing, 5 (12.2%) from the South and 2 (4.9%) from the West. In 1990 the test was moved as previously discussed. There, a total of 304 males were captured. Traps on the East facing captured 110 (36.2%) of these while 94 (30.9%) were taken of the North, 52 (17.1%) on the West and 48 (15.8%) on the South. Prevailing winds in the area are from the Southeast.

Flight Period Study

Of 262 adult male shuckworms captured while monitoring flight periods at hourly intervals after sunset in 1989 and 1990, 180 (68.7%) were taken during the first 4 hours following sunset (114 or 43.5% during the first 2 hours). Fifty (19.1%) were collected during hours 9-12 and the remaining 12.2% (32 moths) were scattered over hours 5-8.

Emergence Pattern Study

A total of 1,368 moths of both sexes emerged from the shucks collected in the Fall of 1988 and monitored throughout 1989. The great bulk of emergence occurred between Mar. 1 and Jun. 1. The count during this primary emergence period was 1,124 (82.2% of the total emergence). Peak activity occurred between Apr. 10 and May 5 (738 moths, 53.9% of total emergence). The additional 244 adults that emerged were scattered over the next 4 months with 117 (8.6% of total emergence) occurring between the dates of July 31 and Sept. 29, when many feel the species causes its greatest damage to the current year's crop.

DISCUSSION

This series of studies provides insight into use parameters for the hickory shuckworm sex pheromone in pecan orchards. Statistical analyses of the data presented here will further this purpose. Based on the unanalyzed data, the following conclusions are offered:

1. Traps may need to be located at least 25 to 30 ft. above the orchard floor.

2. The trap should be hung midway between the tree center and the dripline (although this location produced no more captures than the tree center location, it was observed that more flies, gnats, etc. wandered into the tree center trap, complicating monitoring procedures).

3. Directional facing of the trap may or may not be important (captures were low and the data may be inconclusive).

4. The Pherocon Ic trap appears to be the most effective for monitoring populations of this species.

5. Studies into the nocturnal flight period of activity and the pattern of adult emergence from larval overwintering sites in shucks appear to confirm earlier reports.

Once this data is analyzed, as well as the results of studies not reported here, the authors feel that much of the information necessary to delineate many of the parameters of use for the hickory shuckworm sex pheromone in IPM systems will be available.

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INSECT-PLANT INTERACTIONS WITHIN THE PECAN ECOSYSTEM

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INTRODUCTION

The generalized food web is composed of at least three trophic levels; the plant, herbivore and natural enemies. Each trophic level may influence another, thereby resulting in what is termed 'interactions'. The plant, which is basically a 'chemical factory', is attempting to defend itself from herbivores, while the herbivore is concerned with the extraction of the necessary constituents from the plant for growth and reproduction.

The mechanisms that mediate insect-plant interactions are at least three fold: (1) physically mediated interactions (plant structural and architectural features; i.e., plant hairs or trichomes which function in plant defense against herbivores, or herbivore protection from their enemies, etc.); (2) chemically mediated interactions (plant nutritional and resistance factors; i.e., plant chemistry which provides nutrients to herbivores and natural enemies, or which function in herbivore defense against their enemies, etc.); (3) semiochemically mediated interactions (plant allelochemicals which provide chemical cues for searching herbivores and natural enemies, or which function in plant defense, etc.).

The coevolutionary processes which result in the reciprocal development of chemical defenses by plants and the counter-adaptation to these plant defenses by the herbivore are considered to be the basis for much of the insect-plant specialization seen in nature. Therefore, insect-plant interactions are concerned with the ecological and evolutionary relationships between plants and insects (Spencer 1988).

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CURRENT STATUS OF KNOWLEDGE

Investigations of insect-plant interactions within the pecan ecosystem have been limited in number and generally superficial per se. However, the wealth of knowledge, particularly the observational and survey information associated with selected developmental, behavioral and host selection processes of key pecan pest species (i.e., insect-host plant specificity; insect-host plant synchronicity; host/plant susceptibility; host plant attractancy), forms an invaluable basis for the formulation of questions, the avenues of pursuit, and the ultimate direction for utilization and/or implementation of insect-plant interactions research into pecan management and culture. Following is a synopsis of the pertinent literature which forms such a basis, discussed in relation to the mechanisms which mediate insect-plant interactions.

Physical Features of Pecan. Manning (1950) and Stone (1962) reported that glandular trichome features (i.e., anatomical, chemical, and color) have considerable taxonomic potential within *Carya* species, and therefore might aid in understanding certain insect-plant interactions. Hardin and Stone (1984), in an investigation of foliar surface features of *Carya* species of North America, found that foliar surface features (i.e., trichome type and micro-relief formed by cell contours, cuticular patterns and epicuticular wax) were variable within, as well as among species. Therefore, physical examination of the cuticular or epicuticular wax features, or trichome types (with the exception of the multiradiate type) was not sufficiently or consistently restricted to be reasonably diagnostic and useful in identification of *Carya* species. Therefore, it is doubtful that foliar surface physical features would be useful in determining certain insect-plant interactions within *Carya* spp. However, differences in foliar surface chemistry, not discernible by physical examination, have not been evaluated.

Chemical Features of Pecan. Chemical composition of pecan in relation to tree growth, development and physiology has been reported, with an emphasis on carbohydrate, fatty acid, polypeptide, protein, amino acid, nitrogen, hormonal and oil content of selected pecan tissues (i.e., leaves, fruit, root, shoot etc.) and their association to selected physiological processes (i.e., photosynthesis, senescence, shuck dehiscence, kernel development, shoot growth and alternate bearing). These chemistries, if important in insect-plant interactions, are likely

to exert their primary impact on pecan insect pest species by influencing their growth and reproduction. Therefore, these chemistries would likely be associated with the host suitability component of host selection.

Mody et al. (1976) reported 38 volatile constituents of leaves and immature pecan nuts, including various mono- and sesquiterpene-hydrocarbons, -alcohols, -aldehydes, and -ketones, and other aldehydes, ketones, alcohols and esters. Their studies were initiated to identify those constituents that could conceivably attract pecan weevil to the leaves and nuts. The constituents could also be precursors of the pecan weevil sex pheromone.

Although inconclusive, selected pecan plant constituents have been investigated in regard to their allelochemic nature and function in: (1) phylloxera-pecan interaction related primarily to gall formation (Calcote and Hedger 1980, Hedin et al. 1985); (2) pecan aphid-pecan host plant interactions (Carpenter et al. 1979a, 1979b; Neel et al. 1980, 1982); (3) pecan weevil attraction to pecan fruit (Raney and Eikenbary 1967; Mody et al. 1973); (4) hickory shuckworm attraction to, and feeding stimulation by, pecan shuck extracts (Howell and Maxwell 1969); (5) pecan nut casebearer attraction to exposed stigmatic surfaces (Maden 1972); and (6) pecan aphid attraction to new young pecan foliage (Tedders 1978). Additionally, alleopathy has been reported in pathogen-pecan host plant interactions (Hedin et al. 1979, 1980).

Histological investigations of pecan aphid feeding was reported by Tedders and Thompson (1981) and Wood et al. (1985). Largely qualitative in nature, the impact of pecan aphid feeding on pecan growth and development, and on selected plant chemical constituents (i.e., carbohydrates, etc.) has also been reported.

CURRENT INVESTIGATIONS

The insect-plant interactions investigations currently in progress are focused on: (1) the spatial and temporal dynamics of pecan plant chemistry; particularly those chemistries most likely to function in the host selection processes of the key pecan pest species (Smith et al. 1990a, 1990b, 1990c); (2) the development of sensitive and reliable bioassay techniques and procedures for utilization in substantiating the biological activity or function of the identified pecan plant chemistries (or natural plant products); (3) the role of pecan plant chemistry dynamics in the seasonal population dynamics of the pecan aphid species; (4) the host acceptance and suitability of North American species of Juglandaceae family of nut trees (hickories, walnuts, hicans), as well as a wide range of pecan cultivars, by the pecan aphid species. The primary emphasis of these investigations is centered around the identification of what phytochemical characteristics of pecan influence the selection, allocation and utilization of this host plant by its complex of insect pest species. Secondarily. but equally as valuable, is the identification of natural plant products from both distantly or closely associated plant species which might alter disrupt these insect-plant interactions processes.

ADDITIONAL RESEARCH QUESTIONS AND CHALLENGES

In addition to these current investigations in progress, some of the obvious research questions associated with insect-plant interactions in pecan of more immediate concern are: (1) what role does pecan nut chemistry play in host finding and ovipositional behavior among the key nut infesting pest species (i.e., pecan weevil, hickory shuckworm, pecan nut casebearer, stink bugs); (2) what role does pecan plant chemistry play in the synchronicity of pecan weevil emergence and pecan nut development, or are both factors merely indirectly associated by their regulation by key environmental factors (i.e., temperature, rainfall, etc.); (3) what role does the temporal dynamics of pecan leaf chemistry play in the mid-season population crash and late-season sexual cycle induction among the pecan aphid species (i.e., primarily related to food quality or host suitability for growth and reproduction); (4) what pecan plant and/or aphid characteristics govern the leaf conditioning process; (5) what abiotic (i.e., water stress) and biotic factors (i.e., pathogens) affect aphid-pecan plant interactions; (6) what role does pecan and associated cover crop plant species play in the host selection processes (habitat finding, host finding, host recognition) of the key beneficial insect species (i.e., lacewings, ladybeetles, etc.).

Although these are but a few of the more obvious concerns associated with insect-plant interactions in the pecan ecosystems, the future challenges are many. Natural product analytical chemistry has advanced tremendously in the past 10-15 years. However, continued development of techniques which provide an accurate depiction of the 'intact plant' is vital. Therefore, an understanding of plant biochemistry is critical.

An area of research with major deficiencies and which has failed to keep pace with advances in analytical chemistry is that of bioassay technology. Bioassay is essential for substantiation of the biological activity of the natural products (of plant or insect origin) involved in insect-plant interactions. The identification of the natural product and its function, as well as its ultimate successful utilization in pecan management hinges on the sensitive and reliable bioassay.

Following the development of an understanding of the insect-plant interaction system (both its structures and functions), identification of the more vulnerable links within the system should allow the manipulation, exploitation, and/or interruption of system function. For example, identification of a chemical cue emanating from the pecan nut and used by the pecan weevil in host finding or host recognition might be utilized as a monitoring tool or in combination with an insecticide as a control strategy; for the pecan aphid species, identification of a chemical cue which functions as a feeding deterrent might be utilized to prevent aphid acceptance of, or feeding on, pecan foliage. Although identification of the components of the pecan ecosystem is essential (i.e., what insect pest species are associated with pecan, pecan cultivar, pecan tissue, etc.), expansion beyond the 'what' questions of system structure to the 'how' and 'why' questions of system function is imperative if solutions are to be discovered which work within the system or which are compatible with other pecan management components (i.e., biological control, cultural control, disease management, etc.).

Because nature knows no disciplinary boundaries, multidisciplinary team research is essential; particularly for mission-oriented research where utilization and implementation are considered of paramount importance. Furthermore, insect-plant interactions research must proceed beyond the two-trophic level system and consider more multi-trophic level interactions. For example, pecan and/or its associated plant species may function in a biological control program where they provide searching cues for beneficial insect species. Finally, research should avoid preconceived notions and too narrow a view of natural system interactions. Such a view has more times than not resulted in our inability to transfer new technologies from controlled laboratory test conditions to cropping systems in the field.

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WINTER LEGUMES IN THE TEXAS PECAN IPM PROGRAM

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ABSTRACT

Winter legumes were planted in Texas pecan orchards to evaluate their potential to attract natural enemies of the yellow pecan aphid. During two years of testing, hairy vetch has shown potential for incorporation into a pecan Integrated Pest Management (IPM) program. The most abundant group of natural enemies attracted to legumes were the *Coccinellids*.

INTRODUCTION

One of the major problems facing pecan producers today is the lack of an effective insecticide, or method, to control the yellow pecan aphid complex. This complex includes the blackmargined aphid [*Monellia caryella* (Fitch)] and the yellow pecan aphid (*Monelliopsis pecanis* Bissell). In Texas, where insecticides are applied in most years for the pecan nut casebearer (*Acrobasis nuxvorella* Neunzig) the resurgence of yellow pecan aphids behind insecticide treatments is a major concern.

Yellow aphids have been shown to physically damage pecan by feeding on the vascular system of the leaves (Tedders 1978). Also, public concern about pesticide use and the loss of insecticides for the pecan industry have put a greater emphasis on biological control of insect pests. One area that holds potential for biological control of pecan insects is through habitat manipulation (Tedders 1983). Unlike most agricultural row crops, pecan are not a true monoculture;therefore, offers the potential for interplanting to manipulate insect populations. This strategy has been used in pecans in the southeast (Tedders 1983) and in pear orchards in the state of Washington (Fye 1983).

One group of plants that is well suited for intercropping are the legumes. Prior to the 1960's, summer and winter legumes were part of pecan production systems. During this time the main function of the legume was to supply nitrogen (Blackman 1948, Grossard 1948, White 1981). Although summer legumes were used, producers shifted to winter legumes due to concerns that summer cover crops competed with pecans for moisture.

As part of the Texas pecan (IPM) program, winter legumes were established in demonstration orchards in the fall of 1988 and 1989 to evaluate their potential to attract natural enemies of the yellow pecan aphid complex. In addition to monitoring insect populations, other attributes of legumes such as reseeding ability, maturity time, stand density and ability to suppress weeds were also noted.

METHODS AND MATERIALS

On October 28, 1988, seven winter legumes (Table 1) were seeded in a 242.9 ha pecan orchard in Burleson County. Legumes were inoculated immediately prior to seeding then overseeded into the native vegetation with a cyclone hand seeder at the indicated rates. The soil type for this orchard was a westwood silt loam with a pH of 7.5.

In a nonreplicated test, each legume was seeded between the tree rows from dripline to dripline on both sides of one row of trees. Two middles of native cover were left as a buffer between each legume. Vegetation under the dripline of the trees was not suppressed during the study. Plot size for each legume consisted of two rows approximately 8 m x 250 m each.

At a second demonstration, five legumes (hairy vetch, Cahaba White vetch, alfalfa, Bigbee berseem clover and Clare subclover) were seeded on October 28, 1988 in a clean tilled orchard in Taylor, Texas (Williamson County). Legume seed were inoculated then seeded into a prepared seed bed with a cyclone hand seeder. After seeding, all plots received a light disking to cover the seed. Except for Clare subclover which was seeded in one strip on the outside edge of the orchard, each legume was seeded in the row middles on both sides of one row of trees. Each middle was approximately 6.5 m x 130 m. No buffer area was left between the different legumes. The soil type for this orchard was a Houston clay with a pH of 7.5.

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Sampling for natural enemies was initiated on April 11, 1989 in both Burleson and Williamson Counties and continued until May 30, 1989 or until a cover had matured. Sampling consisted of making 50 sweeps with a 35.56 cm diameter sweep net in each plot.. Insect counts were made directly from the net after each 10 sweeps and natural enemies were tallied according to their group (*Coccinellids, Chrysopids*, spiders, etc.).

In 1989, demonstrations were expanded to orchards in five additional counties (Navarro, Lavaca, Caldwell, DeWitt and Pecos). Legumes planted in 1989 were: hairy vetch, Cahaba White vetch, Bigbee berseem clover, Clare subclover, Mt. Barker subclover, Koala subclover and Tibbee crimson clover. Locations where each of these legumes were planted are listed in Table 2.

Large plot trials were established in Burleson, Lavaca, Navarro and Williamson Counties in 1989 based on evaluating the results of 1988 trials. In Burleson County, hairy vetch was seeded on November 6 over 3.23 ha and Cahaba White vetch, Bigbee berseem clover and Koala subclover on 1.62 ha plots. Seeding of these plots was accomplished with a cyclone hand seeder, seeding into the native clover.

In Lavaca County, Clare and Koala subclovers, Bigbee berseem clover and hairy vetch were drill seeded into a prepared seedbed on December 3, 1989. Plot sizes were: Clare subclover, 3.25 ha; Bigbee berseem, 3.25 ha; Koala subclover, 2 ha; and hairy vetch, 0.4 ha.

At a demonstration orchard in Navarro County, hairy vetch, Cahaba White vetch, Bigbee berseem and Tibbee crimson clovers and Mt. Barker subclover were seeded with a brillion seeder into a prepared seedbed on October 19, 1989. Plots were solid planted with each plot approximately 0.65 ha.

At the 1988 Williamson County site, the hairy vetch plot was expanded to 0.9 ha, while Bigbee berseem was planted over 0.2 ha. Seed were applied with a cyclone hand seeder into a prepared seed bed with both plots receiving a light disking to cover the seed.

Since many native pecan bottoms are grazed in Texas, two demonstrations were established to look at the influence of grazing on legume cover cropping. Demonstration orchards in Caldwell and DeWitt Counties were grazed with cattle during the fall, winter and spring. In Caldwell County, hairy vetch, Bigbee berseem clover and Koala subclover were drill seeded into native vegetation in early December between rows of trees. Each cover was seeded on approximately 1.0 ha.

In DeWitt County, hairy vetch, Bigbee berseem clover and Mt. Barker subclover were seeded in small plots approximately 6 m x 50 m in a mixed improved native and budded orchard. Cattle were allowed to graze during the winter and spring.

Sampling for natural enemies began during April at all locations by making 100 sweeps with a 35.56 cm diameter sweep net in each legume plot. Collections from the net were placed in a container of 70% alcohol and taken back to the office for examination.

RESULTS AND DISCUSSION

1988-1989

In the 1988-89 demonstrations, only hairy vetch, alfalfa and Bigbee berseem clover produced stands that could be sampled. Clare subclover produced a very weak stand in Williamson County and no stands were obtained from subclovers in Burleson County. Red clover at the Burleson County site only emerged in small patches and was not sampled for insects.

Insect counts during the spring of 1989 showed that natural enemies were generally higher in hairy vetch than in other legumes or native cover in Burleson and Williamson Counties. Populations of natural enemies peaked in hairy vetch in Burleson County on May 9, 1989 (Table 3) and on May 2, 1989 in Williamson County (Table 4).

Coccinellids and spiders made up the highest percentage of natural enemies in all covers at both locations. The most common *Coccinellid* collected at both locations was the convergent lady beetle *Hippodamia convergens* Guerin-Meneville. Other common *Coccinellids* collected at both locations were the seven spotted lady beetle *Coccinella septempunctata* L., *Cycloneda munda* (Say) and *Scymnus* (Pollus) *loewii*.

Hairy vetch produced moderate stands at both locations and reduced weed competition except for johnsongrass, *Sorghum halepense* and wild lettuce, *Lactuca* sp., during late May. Hairy vetch had mature seed and could be shredded or disked by the first week of June. Bigbee berseem matured a little earlier, around May 23.

1989-1990

A hard freeze during mid December froze out or severely reduced many of the plots seeded in November. In Burleson County, no stands were obtained in the large plots. Stand failure was due to a combination of the freeze and fire ant activity. The freeze was also responsible for failed stands of subclover in Navarro, Lavaca and Caldwell Counties.

Hairy vetch, which had reseeded from the 1988-89 trials, had two to three inches of growth at the time of the December freeze. The vetch plots received some burning from the freeze but stand density in the spring was unaffected. In fact, stands produced in the spring of 1990 in Burleson and Williamson Counties were much denser than those of the previous year.

Alfalfa produced a good stand in 1989, but was discontinued from the trials because of its season long competition with pecans for moisture.

A hairy vetch demonstration in Pecos County was seeded too late (February) to achieve any fall growth and the stand failed to develop.

In Caldwell and DeWitt Counties where legume plots were grazed, competition from native vegetation and pressure from grazing did not allow stands to develop. Indications from these trials are that legumes planted under grazing may not have the opportunity to generate significant numbers of natural enemies.

Samples of insect populations during the spring of 1990 showed that natural enemies of the yellow pecan aphid were higher in legume plots than in the native vegetation. In Lavaca County, where pecan nut casebearer was treated with chlorpyrifos (Lorsban 4E), natural enemy populations in the berseem plot were reduced but reestablished within two weeks (Table 5).

In Navarro County, Tibbee crimson had high populations of natural enemies early due to the early maturity of the clover. By May 24 both the Tibbee crimson and Bigbee berseem clovers had matured and sampling of these plots was discontinued. One aspect of a cover crop that may be useful is to provide a harborage area for natural enemies during periods when insecticides are applied for the first generation pecan nut casebearer. In this demonstration hairy vetch still maintained predators on May 24 (Table 6), which is about the time for first generation pecan nut casebearer in this area.

After samples were checked for primary aphid predators, they were checked for predaceous thrips. Edelson and Estes (1987) list predaceous thrips of the family *Phaeothripidae* that has been observed to feed on pecan aphids. Most of the thrip species identified from all samples at all locations were in the genus *Frankliniella*. Species of thrips identified were *F. occidentalis, F. tritici, F. fusca, Sericothrips variabilis, Plesiothrips ayarsi, Thrips tabaci, Neohydatothrips cingulatus, Aeolothrips duvali, A. bicolor, Stomatothrips* sp. *A. duvali, A. bicolor* and *Stomatothrips* sp. are predaceous species.

CONCLUSIONS

The results of this work are based on two years of information and a limited number of winter legumes have been screened. It may be possible that summer legumes may have a place in some management systems for increasing aphidophagous insects in the orchard (Bugg and Dutcher 1989). Although several studies on the effects of natural enemies on yellow aphid populations have been conducted (Edelson and Estes 1987, Liao et al. 1984), the full effect of natural enemies coming from cover crops on early season yellow aphid populations requires further evaluation.

One limiting factor that was not examined in these studies was the impact of the red imported fire ant RIFA, *Solenopsis invicta* Buren on natural enemy populations. It has been shown that the RIFA is a major predator of lacewing eggs, larvae and pupae (Tedders et al. 1989) and could be a major limiting factor for any type of biological control program. RIFA were present in all demonstration orchards.

Other aspects of legume cover crops such as reseeding ability, cold hardiness, weed suppression and stand density will be important in an IPM program. It will be just as important to evaluate any limiting aspects of a cover crop. Limiting factors may include soil types, producing nondesirable insects either for pecans or surrounding crops and surrounding crops such as corn or grain sorghum which may compete with pecans for beneficial insects.

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Table 1. Legumes seeded during 1988 at Burleson and Williamson Counties.

Legume	Seeding rate Kg/Ha
Hairy vetch - *Vicia villosa* Roth	28.06
Cahaba White vetch - *Vicia sativa* x *V. cordate*	28.06
Alfalfa - *Medicago staiva*	16.85
Bigbee Berseem clover - *Trifolium alexandrinum*	11.24
Red clover - *Trifolium pratense*	16.85
Clare subclover - *Trifolium subterraneum* L.	11.24
Mt. Barker subclover - *Trifolium subterraneum* L.	11.24

Table 2. Legumes screened during 1990 in different counties.

	Legumes						
County	Hairy vetch	Cahaba vetch	Bigbee berseem	Koala	Clare	Mt. Barker	Tibbee crimson
Burleson	x	x	x	x			
Caldwell	x		x	x			
Dewitt	x		x			x	
Lavaca	x		x	x	x		
Navarro	x	x	x	x		x	x
Pecos	x						
Williamson	x		x				

Table 3. Average[1] number of natural enemies[2] per sweep from Burleson County - 1989.

Date	Hairy Vetch	Alfalfa	Berseem	Bigbee Native
4/11	0.48	0.40	0.84	0.30
4/19	0.34	0.66	1.00	0.42
4/25	0.56	0.42	0.45	0.30
5/2	0.54	0.30	0.12	0.48
5/9	0.96	0.42	0.40	0.16
5/19	0.23	0.26	0.30	0.12
5/23	0.64	0.38	0.32	0.18
5/30	0.22	0.34	----[3]	0.04

[1] Average of 50 sweeps.
[2] All post embryonic stages of *Coccinellids*, chrysopids, syrphids and spiders.
[3] No sample taken because cover had matured.

Table 4. Average[1] number of natural enemies[2] per sweep from Williamson County - 1989.

Date	Hairy Vetch	Alfalfa
4/11	0.14	0.36
4/24	1.82	1.04
5/2	7.00	2.34
5/16	1.00	0.94
5/23	0.34	0.46
5/30	0.24	0.36

[1] Average of 50 sweeps.
[2] All post embryonic stages of *Coccinellids*, chrysopids, syrphids and spiders

Table 5. Average[1] number of natural enemies[2] per sweep from Bigbee Berseem Clover and native vegetation in Lavaca County - 1990.

Date	Bigbee Berseem Clover	Native Cover
4/16	0.44	0.08
4/25	0.18	0.04
5/1	0.36	0.08
5/7[3]	0.33	0.02
5/17	0.04	0.05
5/23	0.58	0.26

[1] Average per 100 sweeps.
[2] All post embryionic forms of *Coccinellids*, chrysopids, syrphids and spiders.
[3] Sprayed for pecan nut casebearer on 5/9/90 with chlorpyrifos (Lorsban 4E)

Table 6. Average[1] number of enemies[2] per sweep from Navarro County - 1990

Date	Hairy Vetch	Bigbee Berseem	Tibbee Crimson	Native
4/10	0.07	0.15	0.17	0.05
4/17	0.20	0.20	0.60	0.15
4/24	0.46	0.31	0.78	0.14
5/1	0.35	0.56	0.54	0.28
5/8	0.69	0.34	0.15	----[3]
5/18	1.41	0.42	0.10	0.04
5/24	0.98	----[4]	----[4]	0.04

[1] Average from 100 sweeps.
[2] All post embryionic forms of *Coccinellids*, chrysopids, syrphids and spiders.
[3] No sample taken because plot was recently shredded.
[4] No sample taken because cover had matured.

DEVELOPING LOW-INPUT MANAGEMENT STRATEGIES FOR NATIVE PECAN ORCHARDS

William Reid[1] and R.D. Eikenbary[2]

ABSTRACT

Low-input strategies offer the only avenue for native pecan producers to increase profitability. The native pecan agro-ecosystem in NE Oklahoma, SE Kansas, and SW Missouri is ideally suited for low input management. Limited insect and disease pressure and a short growing season should enable growers in the three state area to make significant reductions in pesticide inputs. Development of improved crop and pest monitoring techniques can lead to methods for the biological control of overproduction. A total systems approach to crop management is required for future development of low-input management strategies.

INTRODUCTION

Ninety million pounds of pecans are produced annually from seedling trees growing in natural stands throughout Kansas, Louisiana, Missouri, Oklahoma, and Texas (USDA/ERS 1988). Pecans produced from "native" trees represent more than one third of the total U.S. production. In Kansas, Oklahoma, and Missouri, native pecans account for over 90% of the pecan acreage (Figure 1) (Thompson 1984).

Several economic factors are leading to a steady decrease in profits earned from managing native pecans. Over the past 20 years, the price growers receive for native pecans has remained almost constant, while the price of improved pecans (nuts from large, thin-shelled cultivars) has increased slightly (USDA/ERS 1989a) (Figure 2). Adjusted for inflation, grower prices for both native and improved nuts have actually decreased (USDA/ERS 1989b) (Figure 3). In sharp contrast, costs of production inputs have risen dramatically over the same time period (Table 1). With input costs out-pacing increases in nut prices, native pecan producers have three avenues for maintaining profitability: increasing yields per acre, adopting new technologies, and reducing production costs.

Yield of Native Pecans

On a industry wide basis, pecan yield per acre has increased over the last 20 years, as orchards of improved cultivars have taken a larger share of the U.S. production. Limited by the genetic potential of a seedling population, native pecan yield per acre peaks at around 1000 lbs./acre (Reid and Olcott-Reid 1985). Currently, this yield is obtained with an intensive management program that requires large investments in fossil fuels, fertilizer, and pesticides.

Adopting New Technology

The labor and equipment needed for harvesting and cleaning pecans account for 25% of the total production cost (Pena 1987). In the mid 60's, several mechanical harvesters were introduced for use in native pecan groves. These machines have enabled producers to harvest large acreages, while reducing labor costs. Harvesting technology has been refined since that time, but significant changes to allow additional reductions in harvesting costs have not occurred since the mid 70's.

Reducing Production Costs. The leading variable costs associated with the production of native pecans include fuel, fertilizer, pesticides, equipment maintenance, and labor (Pena 1987). Pest control alone accounts for as much as 50% of all variable costs.

In the absence of yield increases or technological breakthroughs, reducing the cost of production remains the only viable approach native pecan producers have to improve profitability. Reducing production costs by substituting biological and managerial inputs for chemical and fossil fuel inputs has been the focus of 'Low Input' agricultural research. Much of the biological information needed to develop a low-input approach to native pecan management is available. Integrating that information into low-input management systems tailored to specific bio-regions offers an exciting challenge for pecan researchers in the 1990's.

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LOW-INPUT AGRICULTURE AND NATIVE PECANS

The expressions, 'low-input agriculture' and 'low-input sustainable agriculture' are among the current buzz words heard in the halls of agricultural academia. But what do these phrases mean? Most commonly, low-input sustainable agriculture is used as a verbose synonym for organic farming. Low-input sustainable agriculture has been defined as a philosophy and system of farming based on a set of values that reflect heightened levels of ecological awareness (MacRae et al. 1989). In practice, low-input sustainable systems avoid the use of synthetically manufactured fertilizers, pesticides, and growth regulators (Pimentel et al. 1989). Crop rotation, green manures, animal manures, cultivation, and mineral-bearing rocks are used to maintain soil fertility. Cultural and biological control measures are employed to check insects, diseases, and weeds. What sets low-input sustainable agriculture apart from low input agriculture is that management decisions in the 'sustainable' system are made within the narrow confines of what is philosophically defined as 'organic'.

Low-input agricultural systems employ many of the same biological and cultural techniques used in 'sustainable' systems but are not limited to purely 'organic' methods. Management decisions in low-input systems are economically based rather than philosophically based. The principles that govern low-input agricultural systems are: (1) adapting crop production techniques to the environment of the bio-region; (2) preserving and enhancing naturally available biological and soil resources; and (3) substituting management skill for prophylactic cultural practices.

Northern Native Pecans: Ideal for the Low-Input Approach. Native pecans thrive in the riparian environments of NE Oklahoma, SE Kansas, and SW Missouri. Commercial orchards, carved from riverbottom forests in this area, are located on the northern edge of the native pecan belt. The growing season in this region is relatively short for pecan, ranging from 190 to 210 days. Heavy, loamy-clay soils dominate most pecan sites in the three state area. Soils are deep, fertile, sub-acid (pH 6.0-6.7), and subject to seasonal flooding. Production problems and practices are quite similar throughout this area, where native pecans dominate the industry (Figure 1).

The native pecan agro-ecosystem in NE Oklahoma, SE Kansas, and SW Missouri is ideally suited for the low-input management approach. Five factors contribute to this ideal suitability:

1. Low economic returns for native pecans provide financial incentive for growers to avoid making expenditures for production inputs of questionable value.

2. Lepidopterous insects that attack pecan fruit and foliage have fewer generations per year in the north. Thus, control measures can be applied less frequently or not at all.

3. Northern native pecans grow under conditions of limited disease pressure. Routine fungicide applications are unnecessary in the area.

4. A permanent ground cover, high soil organic matter content, and optimum soil pH ensure an adequate supply of zinc in northern native orchards. Foliar zinc applications, commonly recommended for Texas native pecans (Johnson et al. 1987), are unnecessary in the three state area.

5. Pecans adapted to fruiting in regions of a short growing season produce seeds that grow, fill, and dehisce in fewer than 150 days from pollination (Reid 1985). This rapid nut development shrinks windows of opportunity through which nut feeding insects attack or injure the nuts.

Keeping these five factors in mind, a low-input management system for northern native pecans can be devised by using current knowledge of pecan tree physiology, integrated pest management, and agricultural economics.

The Native Pecan Agro-ecosystem: A Review

Pecan [*Carya illinoensis* (Wang.) K. Koch] is the largest of the North American hickories. This tree is native throughout much of the central United States, thriving in the flood plains of major rivers in the Mississippi river drainage system (Little 1971). In areas where pecan is endemic, it is often the dominate forest species comprising more than 50% of the native forest biomass (Spencer et al. 1981). Many landowners have taken advantage of this natural resource by developing pecan orchards from the native trees.

Converting a bottomland forest into a productive native pecan grove is a five-step process (Reid and Olcott-Reid 1985). First, all species of trees other than pecan are removed, and the understory is cleared. A permanent ground cover is then established under the trees to facilitate harvest and to prevent soil erosion. After the initial forest thinning process, most native pecan areas are often too crowded for optimum nut production. Old, weak, or diseased trees are removed to allow adequate space for younger, more productive trees. Nut production in the native grove is further stimulated by the annual application of nitrogen fertilizer. And finally, an insect management program is initiated to prevent serious yield losses from nut feeding insects.

All cultural practices applied to native pecan groves are to promote high annual nut production. Even with superior management, native pecan orchards have a strong tendency towards irregular bearing (Figure 4). The unreliable annual supply of seedling pecans inhibits food processors from developing additional products that utilize seedling pecans. This absence of new product development contributes to depressed grower prices for native pecans.

Several internal and external factors influence seed production in pecan. An understanding of how these factors interrelate is needed before new cultural practices, including low input strategies, can be developed to reduce irregular bearing and improve grower profitability.

Internal Factors: The Cropping Cycle

Pistillate flowers of pecan trees are borne on terminals of the current season's new growth (Brison 1974). Although no morphological evidence of pistillate flower initiation can be found until after growth commences in the spring (Wetzstein and Sparks 1984), flowering intensity is determined during the previous growing season through the influence of seed production on tree physiology (Smith et al. 1986) (Figure 5). During growth and development, pecan seeds pull large amounts of carbohydrates from surrounding plant tissues (Davis and Sparks 1974). This carbohydrate drain limits the amount of energy available for pistillate flower initiation in the following year.

External Factors Affecting Pecan Yield

Native pecan yield is influenced by weather, tree spacing, weed competition, soil fertility, diseases, and insects. These factors influence pecan yield at two points in the cropping cycle (Figure 6). Drought and early-season, nut-feeding insects can cause significant nut abortion, thus influencing yield directly. Tree overcrowding, weed competition, low soil fertility, foliar diseases, and foliage-feeding insects influence yield indirectly by reducing tree vigor and photosynthetic efficiency.

As discussed earlier, the primary focus of native pecan management has been to minimize the impact of all external crop-reducing factors. This approach has been only moderately successful in reducing alternate bearing (Sparks 1983). Further advances in pecan yield regulation will be made only after cost effective methods for thinning heavy crop loads are developed.

Nut-Feeding Insects

Pest control efforts in native pecan groves are aimed at three major nut-feeding insects; pecan nut casebearer (*Acrobasis nuxvorella* Neunzig), hickory shuckworm [*Cydia caryana* (Fitch)], and pecan weevil [*Curculio caryae* (Horn)]. Although pecan weevil is the most serious pest native pecan producers face (Payne et al. 1979), this insect attacks nuts after seed development is largely completed (Harris 1985) and has little impact on the pecan cropping cycle. Pecan nut casebearer and hickory shuckworm cause nuts to abort before seed development is complete (Payne et al. 1979). This nut thinning directly affects the pecan cropping cycle and may offer a possible biological solution to overproduction problems.

MAKING A LOW-INPUT PROGRAM WORK

In developing a low-input management program for northern native pecan orchards, an analysis of current inputs is necessary in order to identify potential areas for input reductions. Production costs for the typical northern pecan grower include nut harvest, nitrogen fertilization, and insect control.

As mentioned previously, nut harvest consumes 25% of all variable costs. In the absence of new technologies, harvest costs must increase with increases in costs for machinery, fuel, and labor. Reductions in harvests costs are not on the horizon for any management system.

Nitrogen Fertilization

Native pecan orchards respond to nitrogen fertilization with considerable yield increases (Reid 1990a). Trees in well spaced groves will respond within 2 years of the initial nitrogen application. Nitrogen application may be the most profitable cultural practice used to increase native pecan yield. If the cost of urea (45% N) is $170.00/ton (1990 price) and a grower applies 225 lbs. urea/acre (100 lbs.N/Acre), he will spend $19.13/acre on fertilization. The application of 100 lbs. N/acre to native pecans increases yield by an average of 200 lbs./acre. If native pecans are sold for $0.45/lb., fertilization will return $90.00/acre in increased nut production and $70.87/acre in profit.

As long as the price for manufactured nitrogen remains relatively low, there is little incentive to develop alternative soil-fertility management systems. Increasing prices for fossil fuel used in the manufacture of chemical nitrogen and growing public concern for nitrogen contamination of ground water resources may alter this situation. If future events precipitate large increases in the cost for applying chemical nitrogen, native pecan growers will be among the first to turn to nitrogen-fixing cover crops as a low input alternative. The nitrogen-fixing capacity of forage legume crops is well known (Brady 1974). The ability of orchard-grown legumes to provide all the nitrogen needed to sustain high yields is a question that needs further study.

The incorporation of legume cover crops in the pecan agro-ecosystem also has important pest management ramifications. Legumes provide a nursery for the *in situ* proliferation of beneficial insects that can be manipulated for the control of pecan aphids (Tedders 1983). Successful aphid biological control programs using legume cover crops have been employed in south Georgia (Bugg and Dutcher 1989, Tedders 1983). In the north, pecan aphids are only an occasional pest and are rarely the target of chemical control measures. Naturally occurring beneficial insects keep aphids in check during most years in Kansas (Dinkins and Reid 1985). For legumes to become part of a soil fertility program for northern low-input orchards, the influence of this cover crop on insect populations (both harmful and beneficial) must be studied carefully to ensure that total inputs for nitrogen fertilization and insect control are reduced.

Insect Control

With pesticide prices increasing fourfold from 1970 to 1990 (Table 1), limiting their use on native pecans could significantly reduce production costs. The primary targets of the insecticides applied to native pecans in the north are pecan nut casebearer, hickory shuckworm, and pecan weevil. Because these insects have tremendous destructive potential, insecticides are applied 4 to 5 times a year under the assumption that economically damaging populations occur every year (Gallott et al. 1988, Morrison et al. 1982). For native pecan orchards that have had a high level of management for many years, this assumption may be invalid. During years of overproduction, pecan nut casebearer and hickory shuckworm may actually play the much needed role of nut thinning agents. Late in the late season, pecan weevil populations may be driven so low by years of pesticide application that further applications are not economically justified.

Scouting procedures have been developed for all the major insect pests of pecan (Reid 1988). Unfortunately, too many native pecan managers still apply prophylactic sprays without prior information on pest population levels. Low input strategies can work only after growers learn to substitute investments in management effort for investments in routine pesticide applications of questionable benefit. Intelligent decision making about pest management requires an intimate knowledge of insect and host plant biology and accurate scouting methods for determining economic injury levels.

Insect and Crop Load Monitoring

The success of a low-input, pecan-management program hinges on our ability to weigh insect control costs (both economic and biological) against potential income loss. In spite of recent advances in pecan pest management, native pecan growers are often faced with making pest control decisions without the benefit of accurate economic injury information. A brief look at the management of two nut feeding insects points out weaknesses in current IPM practices.

Pecan Nut Casebearer

A growing-degree day model (Ring et al. 1983) and sequential sampling plan (Ring et al. 1989) have been proposed for pecan nut casebearer. The growing-degree day model has had some success in estimating a best ‘spray date’ for control of this

insect, whereas the sequential sampling plan attempts to determine the need for control. Both techniques are based on determinations of percent nut clusters infested with pecan nut casebearer. The expression of damage in percent infested clusters may accurately reflect insect behavior but is not easily converted to nut loss estimates. The discrepancy between percent infested clusters and percent nut loss can be seen in Table 2. Regardless of how percent damage is expressed, lack of accurate estimates for nut load renders percent damage information useless for determining economic injury levels. Percent nut loss to pecan nut casebearer was similar in 1986 and 1987 (16.7% and 16.9% respectively), yet nut yield per acre was three times greater in 1987 than in 1986 (Reid 1990a). In 1987, 16% nut loss would have provided a beneficial level of nut thinning to reduce overproduction. In a low crop year such as 1986, 16% nut removal by casebearer represents a significant economic loss.

Accurate estimation of pecan yield potential will be crucial to the future of biological control of seed overproduction (i.e., allowing pecan nut casebearer to thin pecan fruit). A recent attempt to estimate yield (Wright et al. 1990) has limited application to native pecan systems. The authors found significant differences between yield estimation models for different cultivars, years, and sites. Because of the immense genetic diversity in a native pecan grove, yield estimation models must be developed from large scale data bases. The management decisions native pecan managers make are for large acreages (100 to 1000 acres). Methods to estimate the yield potential of a 100-acre native pecan grove would be sufficient to determine economic thresholds and make pest control decisions.

Hickory Shuckworm

The current pest management approach to controlling hickory shuckworm can best be described as the "also" approach. Native pecan producers rarely apply a pesticide with the exclusive objective of controlling shuckworm. In Kansas and Oklahoma, native pecan growers often make a prophylactic insecticide application in early July to control insect pests such as walnut caterpillar, fall webworm, hickory nut curculio, and "also" hickory shuckworm (Gallot et al. 1988, Morrison et al. 1982). In August, insecticides applied to control pecan weevil "also" control hickory shuckworm.

As low-input strategies are adopted and pesticide applications are reduced, will hickory shuckworm become a more prominent pest? In the north, the hickory shuckworm has three generations per season (Dinkins and Reid 1988). The overwintering generation emerges before nut set and does not injure pecan. The first summer generation is usually so small that nut drop caused by this insect is negligible. Larvae from the second summer generation mine nut shucks and have been shown to inhibit nut fill. In a survey of 146 native pecan trees from a single orchard in SE Kansas, I found 25% of all nut shucks infested with shuckworm larvae (Reid 1990b). However, infestation rate could not be related to decreases in nut fill (Figure 7) or number of indehiscent nuts. Shuckworm larvae may not pose a significant threat to kernel fill in the north, where pecans are adapted to a short season climate. Northern natives fill their kernels before shuckworm larvae grow large enough to reduce the flow of carbohydrates to the seed.

The apparent differences in potential damage from hickory shuckworm between northern and southern pecan regions point out the importance of developing management strategies for specific bio-regions. Collection of basic biological information on all agro-ecosystem components is necessary for the development of site-specific, low-input strategies.

FUTURE RESEARCH NEEDS

Implementation of low-input management systems is dependent on total agro-ecosytem research programs. History provides painful evidence of how narrowly focused research can lead to economic disasters for growers who rely on university research for production guidelines. The pecan aphid problem that currently plagues southeastern pecan growers was created by the overuse of pesticides. After nearly 20 years of attempts at chemical quick fixes, scientists have adopted the total agro-ecosystem approach as the only sustainable solution to aphid management (Tedders 1986). Research opportunities abound for pecan scientists wishing to develop low-input pecan-management systems. An integrated approach to crop load estimation and pest monitoring techniques should become a research priority across the pecan belt.

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Table 1. 1970 and 1990 producer price indexes for selected equipment and supplies used in native pecan production. Source: U.S. Dept. of Labor, Bureau of Statistics. 1967=100.

Commodity	1970	1990
Farm Implements	115.3	331.0
Oil Products	103.1	413.1
Nitrogen Fertilizer	65.1	163.4
Pesticides	108.5	435.4

Table 2. Pecan nut casebearer damage expressed as percent infested clusters and percent of nuts lost. Data collected from 200 nut clusters on 10 native pecan trees growing in SE Kansas in the years 1981 through 1987.

Year	Percent Infested Nut Clusters	Percent of Nuts Damaged
1981	11.5	9.1
1982	28.5	19.8
1983	7.0	3.3
1984	32.5	22.0
1985	34.0	26.4
1986	25.5	16.7
1987	27.5	16.9

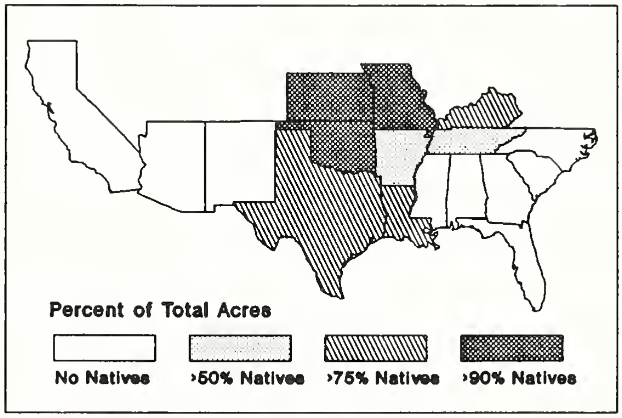

Figure 1. The importance of native pecans in pecan producing states.

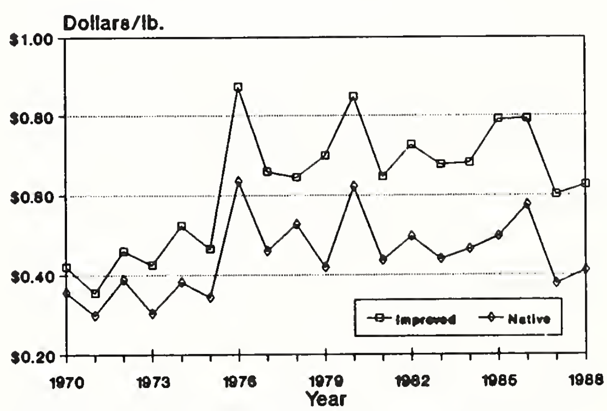

Figure 2. Prices paid to growers of native and improved pecans in the U.S. for the years 1970 through 1988.

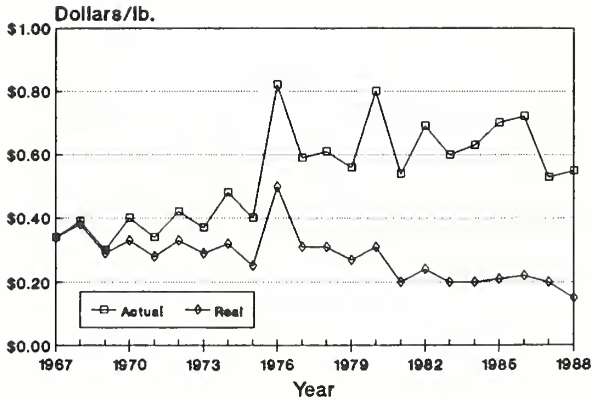

Figure 3. Grower prices for all pecans in actual and real dollars. The price paid to growers are expressed in actual dollars. The price paid to growers after adjustment for inflation are shown in real dollars.

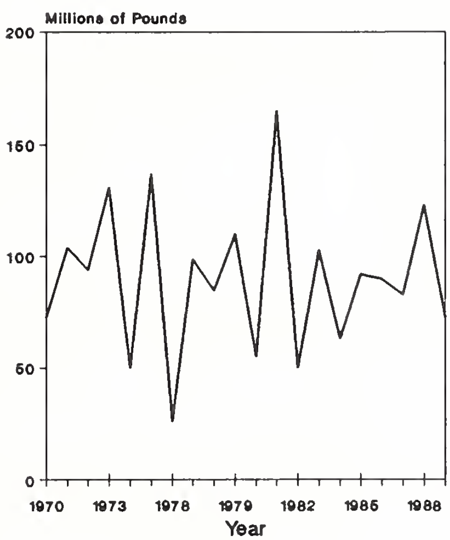

Figure 4. Total U.S. native pecan production for the year 1970 through 1989.

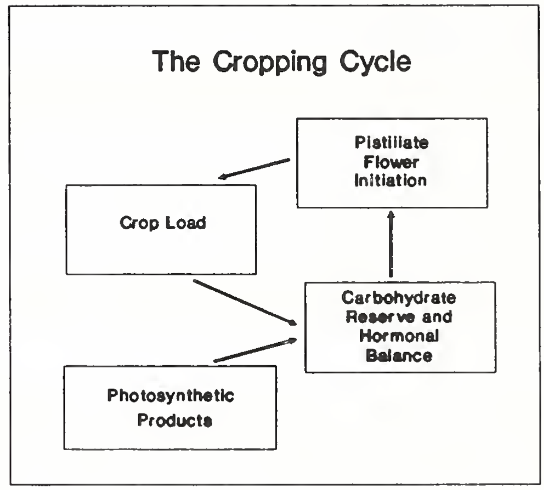

Figure 5. A schematic representation of the pecan cropping cycle.

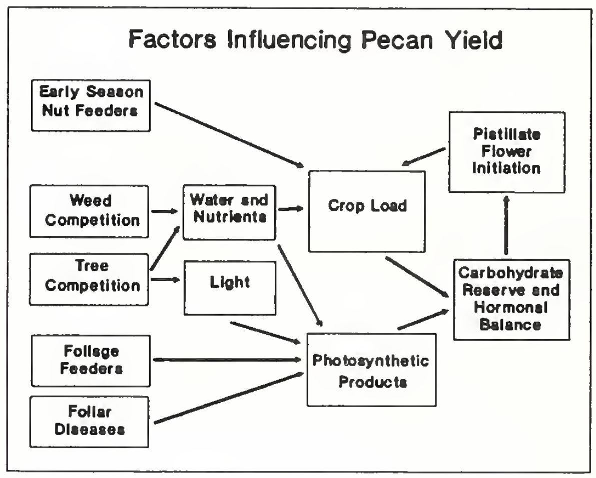

Figure 6. The external factors that affect the pecan cropping cycle.

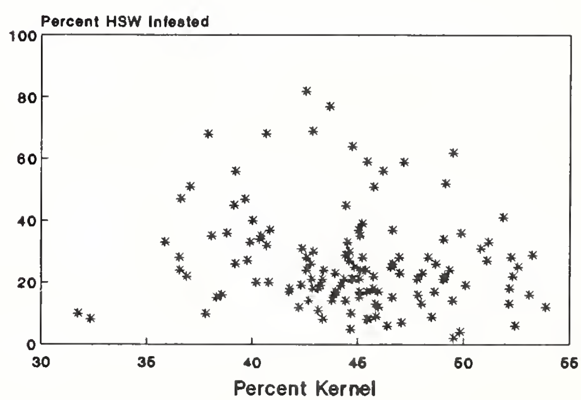

Figure 7. The relationship between hickory shuckworm infestation and kernel quality for 147 native pecan trees growing in SE Kansas in 1988.

ALTERNATIVE CONTROLS FOR PECAN INSECTS

W. Louis Tedders[1]

The culture of pecans offers an excellent opportunity to demonstrate control of aphids and other pests by a number of alternatives to synthetic chemical sprays. However, it is unlikely that growers can produce pecans consistently and profitably without occasional, strategic use of some pesticides. Acceptance of alternative measures by growers may be difficult but likely will be necessary in pecan culture.

The purpose of this presentation is to describe current research on alternative controls, to introduce several new and/or controversial ideas, and to stimulate discussion of the potential of alternatives for pecan pest control. The concepts presented are not necessarily the opinions of and should not be taken as recommendations by, the USDA-ARS.

Alternative controls for pecan insects will be categorized as chemical, cultural, physical, and biological. These categories are rarely clear-cut, and usually have some overlap and impact on each other. The use of these alternatives by growers will include the integration of various combinations or parts of each. Some of the alternatives may be impractical for use by growers. The development of effective alternatives will prove to be a long and difficult process.

Chemical Alternatives

Broad spectrum pesticides have been beneficial as control agents in past years and the total abandonment of these chemicals is unlikely if not unwise. However, the days of indiscriminate use of broad spectrum pesticides seems to be drawing near. Perhaps reducing the use of chemical pesticides is for the best because the total chemical philosophy creates about as many problems as it solves.

Certain broad spectrum pesticides should still have value, when and if natural controls fail, when parasites of beneficial species must be reduced in numbers because of being overly abundant, when additional information reveals the need for growers to revamp control measures, or when the need arises for other unforeseen reasons. For example, a broad spectrum pesticide application to the orchard floor for control of certain pests may not have the same effect as its application to the tree canopy. This usage has not been fully explored. Perhaps pesticides can be used in this manner that are not permitted for use in the tree canopy.

A need exists for the chemical industry to develop a new arsenal of selective pesticides having minor or moderate effect on non-target species. During development, consideration should be given to the effect on beneficial, as well as pest species. Unfortunately, the costs for developing such chemicals will be great and the probability of rapid success is remote unless standards set by the Environmental Protection Agency and the Food and Drug Administration are relaxed.

Information available about the effects of currently recommended pesticides on the complex of beneficial species on pecans, with the exception of work by Mizell and Schiffhauer (1990), is scant. This type information is vital for development of effective alternatives. Although an excellent guideline based upon existing knowledge (Ellis et al. 1984) is available, improved guidelines will be needed for determining the least harmful pesticides for use during a given situation, for improved pest and beneficial insect sampling techniques, and for determining economic numbers of pests to minimize the use of pesticides. The points of diminishing returns to growers relative to incurred damage by pests when compared with the costs for sprays is the poorest studied area in pecan culture. Also, this information will likely be the most difficult to develop and to convey to growers.

Needs for other important chemical alternatives include the development of semiochemicals such as sex pheromones, kairomones, anti-feeding compounds, baits, repellants, growth inhibitors, sex sterilants, and juvenile hormones, to name a few.

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One notable advancement in this area in the recent characterization of the sex pheromone for hickory shuckworm, *Cydia caryana* (Fitch) by M.T. Smith (1985) and the subsequent development of a commercial product for sampling the presence of male shuckworm moths. This work will lead to a considerable reduction in insecticides applied for this pest.

Other important Lepidoptera on pecan that probably have female sex pheromones include pecan bud moth, *Gretchena bolliana* (Slingerland), pecan nut casebearer, *Acrobasis nuxvorella* Neunzig, pecan leaf casebearer, *Acrobasis juglandis* (LeBaron), fall webworm, *Hyphantria cunea* (Drury), and walnut caterpillar, *Datana integerrima* Grote and Robinson. Sex pheromones for each of these could and should be characterized as soon as possible. With the current knowledge of the subject and availability of modern technology, this task should not be very difficult. Characterization of a sex pheromone for the coleopteran pecan weevil, *Curculio caryae* (Horn), may be difficult since several researchers have tried and failed.

Honeydew produced by aphids is a major food source for many insects and its presence may be necessary for attracting and retaining large numbers of many beneficial species. If the chemical attractant in honeydew can be characterized, then this alone may open the door for manipulation of many beneficial species.

Presently there are no baits recommended for use in pecans for control of red imported fire ants, *Solenopsis invicta* Buren. Used properly, baits are very effective. Several baits for fire ants have been developed, including fenoxycarb (Logic), abamectin (Affirm), and hydramethylnon (Amdro), but none have been labeled for pecan culture. Imported fire ants were recently shown to be major predators of certain beneficial species (Tedders 1990) and their their management is necessary for the development of alternative measures.

Cultural Alternatives

Cultural practices used in the pecan orchard that may have an impact on the presence of insect pests include maintaining (1) cover crops to serve as alternate host plants for beneficial species, (2) proper sanitation measures to reduce sites for overwintering larvae, (3) the orchard perimeter to control migrating pests, and (4) proper soil moisture and orchard humidity to provide suitable environments for sporulation of beneficial fungi. Integration of these practices into orchard management may reduce the need of chemical controls.

Cover crops. Most commercial pecan orchards are frequently mowed and routinely sprayed with both herbicides and pesticides. As a result, plants and animals in the orchard ecosystem are reduced by both numbers and diversity. Under these conditions of essentially a monoculture of trees, insect pests with resistance to sprays will increase rapidly because competition by other species and other natural controls are absent. The situation presently exits with aphids, mites, and leaf miners on pecans. Theoretically, the monoculture effect can be reduced by planting within or around the orchard, ground cover crops, perennial shrubs, and various annual plants which serve as sources for alternate supplies of food and refuge for beneficial species. Foods there include insect prey, honeydew, extrafloral and floral nectary secretions, and pollen. The preservation and enhancement of selected weed species can have similar effects.

Several winter cover crops (Tedders 1983), summer cover crops (Bugg and Dutcher 1988), and crape myrtle shrub (Mizell and Schiffhauer 1987) have been investigated for this purpose. Promising winter covers include vetch, clover, and alfalfa spp., Austrian winter peas, and English peas. Summer covers include joint vetch, *Sesbania* sp., cowpea, *Sorghum* sp., and buckwheat. Of these plants hairy vetch, *Vicia villosa* Roth, common vetch *Vicia sativa* L., crimson clover, *Trifolium incarnatum* L., *Sesbania exaltata* (Rafinesque-Schmaltz), and crape myrtle, *Lagerstroemia indica* L. seem to be the most promising.

Planting hairy vetch as a cover crop to provide a niche for the development and reproduction of ladybeetles, including *Hippodamia convergens* (Guerin-Meneville) and *Coccinella septempunctata* L. is an example of a cultural alternative to chemicals for controlling aphids. When aphid prey on vetch are depleted, the beetles migrate into pecan tree, and there consume, aphids, mites, and other pests. It is likely that over time these beetles move back and forth between trees and ground cover. In some instances nectar and pollen of certain plants may also help attract and retain beneficials within the orchard vicinity during the absence of prey on pecan trees. Also, cover crops of legumes are capable of supplying at least part of the nitrogen requirements of pecans (White et al. 1981). Alfalfa, crimson clover and other cover crops hold

promise for producing hay or forage, seed, and nectar for honey bees, all of which could supplement the grower's income. Winter cover crops improve the water and oxygen permeability of soil and the remaining mulch reduces soil erosion and preserves soil moisture. Cover crops and mulch also improve the orchard environment for many non insect arthropod and vertebrate predators. In addition to cultivated crops, a number of natural weed species including *Erigeron canadensis* L. and *Solidago* spp. are promising as food and refuge sources for beneficial spp.

Orchard Sanitation. Sanitation is a technique that has been badly neglected by pecan researchers and growers. Studies conducted during the 1940's indicated that hickory shuckworm infestations were reduced 50% by plowing into the soil, shucks infested with overwintering larvae (Monzette 1941). Presently plowing and tilling pecan orchards is not practiced by most growers. However, most pecan shucks in mechanically harvested orchards are passed through machinery during nut harvest operations and then returned to the orchard floor. The development of harvest equipment to destroy infested shucks should not be difficult. Conversely, equipment could be developed to collect infested shucks, which also contain parasitized shuckworms. These could provide a source for thousands of parasites including Tachinidae, Ichneumonidae and Braconidae. The shucks could be stored in cages to allow emergence of the parasites during the time period that is slightly different from that of shuckworm moths. Collected parasites could be released back into the orchard and the remaining shuckworms could then be destroyed.

With decreased use of insecticides, pecan growers will likely see an increase in the number of insect species that attack limbs branches and twigs of pecan trees. These pests include longhorned borers (Cerambycidae), metallic woodborers (Buprestidae), false powderpost beetles (Bostrichidae), and engraver or bark beetles (Scolytidae). Many of these species complete their life cycle within dead or weakened limbs that remain in trees and within branches and twigs that have fallen to the ground. Dead and weakened limbs should be pruned from the trees and branches and twigs should be gathered. Both should then be removed from the orchard and burned or otherwise destroyed. As these insects generally attack weakened and stressed trees, the best preventative measure is to keep the trees in a vigorous and healthy condition through the use of an adequate fertilizer and irrigation program.

Orchard Perimeter. Many insect pests, especially those attacking weakened limbs and a number of weevil species, breed in nearby hardwood stands and then move into adjacent orchards for feeding. Steps should be taken to remove the outside sources of these pests. Good examples are the migration of the pecan curculio, *Conotrachelus hicoriae* (Schoof) and *Conotrachelus schoofi* Papp from wild hickory stands and from fence rows. These usually attack the shoots and fruits of border trees of orchards most severely.

Other pest species that migrate into pecan orchards include stink bugs (Pentatomidae) and leaffooted bugs (Coreidae) which move from matured vegetable and field crops as well as from weed fields to alternate host plants in late summer. Pecan fruits are alternate hosts for many of these pests and thus receive significant damage each year. Here again, fruits in border trees usually receive the most damage. Preferred host plants for stink bugs and leaffooted bugs can be planted adjacent to pecan orchards to attract migrating bugs and to arrest future movement. There the arrested bugs can be killed with pesticides to prevent their future movement into pecans. The alternative use of "trap crops" has been studied for bug control on other agricultural crops and needs investigation for use with pecans. Blacklight traps placed around the periphery of orchards may be used to survey for their presence and may reduce their damage.

Irrigation

Irrigation is known to enhance the production of pecans but it has not been studied for the effect on pecan pests. For example, irrigating to raise the moisture level of orchard soil may increase the incidence of introduced or natural diseases of pests. Many important entomopathogens germinate and sporulate only in the presence of high humidity. Frequently after several days of extended rain and cloudiness, many species of dead insects having heavy sporulation of *Beauveria bassiana* (Balsomo) Vuillemin can be found within the mulch and litter on the orchard floor and beneath bark on the trees. Considerable background research has been done with the entomopathogens *B. bassiana* and *Metarhizium anisopliae* (Metschnikoff) Sorokin against pecan weevils (Tedders 1985). Results indicated that these fungi could effectively control weevils under the proper conditions. The factor apparently limiting the usefulness and effectiveness of these fungi is adequate moisture to insure timely sporulation and spore germination.

One hypothetical use of these fungi is to infect pest insects such as alfalfa weevil, *Hypera postica* (Gyllenhal) on vetch or alfalfa cover crops growing in the orchards. Sporulating cadavers of these weevils could then serve to raise the inoculum level in the orchard for alternative control measures of pecan weevils.

Irrigation may also be use to disseminate entomophagous nematodes including *Neoaplectana carpocapsae* Weiser (Tedders et al. 1973) and *Heterorhabditis heliothidis* (Nyczepir 1989). Both species attack pecan weevil larvae and are being investigated at this time. A moist environment associated with irrigation likely would enhance their survival and effectiveness.

Physical Alternatives

Physical methods are generally considered to be engineered devices such as traps and barriers. These instruments are usually constructed to utilize heat, light, sound, or air for repelling, trapping or killing pests. Blacklight traps are a good example and have been used to suppress hickory shuckworm populations in pecan orchards (Tedders et al. 1972) but the expense required for large numbers of blacklight traps, wiring, and energy may not be cost effective for large producers. Also examining trap collections for small or delicate insects is difficult. However, blacklight traps may be useful for control purposes for growers with small orchards or homeowners with only a few trees. Blacklight traps of various designs are now available through many department and hardware stores. Blacklight traps can be effectively used as survey tools by large growers to detect a number of important pecan pests including fall webworm, walnut caterpillar, may beetles (Scarabaeidae), stink bugs, leaffooted bugs, and longhorned beetles. Although difficult to use as control devices, blacklight traps are very good tools for surveying for pecan nut casebearer, fall webworm and pecan leaf casebearer. Until pheromone traps are developed for some of these species, blacklight traps may be the best detection method that is available. With reduced usage of broad spectrum pesticides, some of the above listed pests will likely return to prominence and growers will need detection devices.

Barriers also may have a place as physical alternatives to chemical sprays in control of pests. Research is needed on the effects of various barriers around tree trunks for capturing, killing, or preventing the migration of pecan weevil adults up tree trunks. While trunk barriers alone may not provide a high degree of weevil control, this technique could significantly lessen their attacks.

Research is also required to develop physical barriers on the soil beneath trees to prevent entry of weevil larvae and the emergence of weevil adults. Soil coverings of diatomaceous earth, fiberglass, or inexpensive screen beneath trees may serve as barriers against weevil larvae and adults. Pecan weevils have long been considered one of the most difficult pest problems for growers and they are a major stop-gap in the development of a good alternative control program for aphids. Developing an effective alternative method for control of pecan weevil will demand a long-term research effort because of the 2 and 3 year life cycle of this pest.

Also studies are needed on the use of barriers to prevent ant species from moving into pecan trees. Red imported fire ants were demonstrated recently to move into pecan trees and forage on the eggs, larvae, and pupae of the green lacewing, *Chrysoperla rufilabris* (Burmeister) and the puparia of the syrphid, *Allograpta obliqua* (Say) (Tedders et al. 1990). Lacewings and syrphids are important natural enemies of the aphids on pecans. This behavior by fire ants results in the increase of pecan aphids. Aphids in turn produce large amounts of honeydew. Fire ants collect honeydew which also is a major part of their food supply. Barriers to prevent the foraging on pecans by red imported fire ants would provide logical alternatives for their management. Barriers on fruit trees against various ant species are commonly used in other parts of the world and especially in South Africa (Samways and Tate 1984).

Presently we are studying the effects of light on the development of sexual forms of pecan aphids. Hopefully we will find that interruption or alteration of the scotoperiod will interfere with the normal development of sexual forms during September and October. Sexuals of female aphids lay eggs, which are overwintering forms. If egg production can be prevented then cold weather in November should kill the remaining asexuals, providing control during the following spring.

BIOLOGICAL ALTERNATIVES

The production and development of beneficial species on cover crops has already been discussed. The use of cover crops may be enhanced by liberating commercially available beneficial

species such as ladybeetles (*H. convergens*), lacewings (*Chrysoperla* spp.), and parasitic wasps (*Trichogramma* spp.) within the orchard to insure a timely start and to supplement the naturally occurring population of these species.

Paper wasps (Polistes spp.) are important predators of various insect pests especially foliar feeding caterpillars, and their habitat is easily improved in orchards. Wasps can be increased in numbers by stationing small wooden boxes with open bottoms throughout the orchard. The boxes can be attached to wooden poles or to tree trunks. Wasps build their nests in the boxes without further encouragement.

While imported fire ants may create aphid and scale insect problems (Tedders et al. 1990), they are very efficient predators known to attack many insects including pecan weevil larvae (Dutcher and Sheppard 1981). With the present availability of fire ants in most southeastern pecan orchards, these predators may be manipulated for use against weevils, shuckworms, certain leafminers and possibly other pests. Barriers designed to prevent fire ant movement into trees would be a means of manipulating the behavior of this potential pest for control of a number of insects on the orchard floor.

Certain species of insectivorous birds including bluebirds and swallows may be increased within or near orchards by providing nesting boxes and water (Tedders 1985). Other bird possibilities include domesticated fowl such as chickens, turkeys, and Guinea fowl as predators of pecan weevils. However, the use of large numbers of domesticated fowl may cause bacterial contamination of nuts from fecal matter.

Significant research has been devoted to the release and establishment of exotic beneficial insects, especially ladybeetles for pecan aphid control. Species evaluated to date include *Harmonia axyridis* Pallas from Japan, *Harmonia conformis* (Boisduval) from Australia, *Propylea japonica* (Thunberg) from South Korea, *Calvia quatuordecimguttata* L. from Japan, *Hippodamia variegata* (Goeze) (as *Adonia variegata*) from the USSR and *Coccinella septempunctata* L. from New Jersey (European origin). Only the latter species became established and provides minimal control of aphids on pecans (Tedders and Angalet 1981). As of 1989, APHIS/USDA recovered *C. septempunctata* from most states east of the Rocky Mountains and they released the species in Idaho, Nevada, California, Arizona, Utah, and Washington during 1989.

Trioxys pallidus (Haliday), a parasite of the walnut aphid, *Chromaphis juglandicola* (Kaltenbach), and *Trioxys complanatus* Quilis, a parasite of the spotted alfalfa aphid, *Therioaphis maculata* (Buckton) from California were released at Byron, Georgia several years ago as parasites of the blackmargined aphid, *Monellia caryella* (Fitch), the yellow pecan aphid, *Monelliopsis pecanis* Bissell, and the black pecan aphid, *Melanocallis caryaefoliae* (Davis) (Tedders 1977). Thereafter a new species, *Trioxys monelliopsis* Stary and Marsh, became established at the release site. It is likely that *T. monelliopsis* is a biotype of one of the original releases since it was found only at Byron, GA for many years. It is also possible that it is a hybrid resulting from a cross between *T. pallidus* or *T. complanatus* with a local species. *T. monelliopsis* fluctuates in numbers each year and provides minimal control of aphids on pecans.

The aphid parasite *Aphelinus perpallidus* Gahan occurs in fairly large numbers throughout the pecan growing region. This species is very tolerant of many insecticides (Mizell and Schiffhauer 1990) and is a prime candidate for manipulation and enhancement in the field.

Pecan aphids and the pecan leaf scorch mite, *Eotetranchus hicoriae* (McGregor), represent a major threat to pecan growers. Both are insecticide-induced species that are normally held in check by natural controls. Aphid numbers should decrease if applications of broad spectrum insecticides can be reduced and fire ants are controlled. Aphids and mites have high reproductive rates and rapid life cycles which enhance their genetic selection, resulting in tolerance or resistance to frequently used insecticides. Their greatest numbers occur naturally during the same time period as pecan weevils. To further complicate the aphid-mite dilemma, carbaryl, the only insecticide that effectively controls pecan weevils, is a broad spectrum pesticide. Aphids and mites are resistant to carbaryl and serious outbreaks usually occur after its use (Dutcher and Payne 1983). The migration of new beneficial species into a carbaryl treated orchard is of little consequence since these are unable to consume more aphids or mites than are being produced. Also, carbaryl residues may continue to kill immigrant beneficials for a number of days. Aphid and mite numbers eventually diminish as a result of crowding, competition for food, the urge to migrate, and the conditioning or death of tree foliage. Developing an alternative control for

pecan weevils is imperative to designing alternative control for aphids, mites and other pecan pests during the latter part of the growing season. This problem is among the most needed research for the culture of pecans.

The preceding information represents only a minute part of the potential for alternative measures for the pecan culture. There are literally hundreds of other possibilities, limited only by the imagination of pecan researchers and the number of people available to do the work.

In closing, one of the greatest threats to the development of workable alternatives for pecans is that of overzealous opportunists in the commercial alternative control business. Nothing will shatter the confidence of growers more quickly than the sale of systems of organisms that have little or no chance of working. There already is evidence that this may be happening. On the other hand, most commercial alternative control businesses have the best interests of the pecan industry at heart and most of these people are supportive, cooperative, and helpful.

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TRICHOGRAMMA PRETIOSUM TESTED AS A BIOLOGICAL CONTROL AGENT AGAINST THE HICKORY SHUCKWORM

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ABSTRACT

The egg parasitoid *Trichogramma pretiosum* Riley readily parasitized hickory shuckworm (HSW) [*Cydia caryana* (Fitch)] eggs in the laboratory, but failed to control hickory shuckworm in the orchard. HSW moths were allowed to oviposit on nuts in the laboratory. These eggs were exposed to *T. pretiosum* in the laboratory where at least 90% were parasitized. However, *T. pretiosum* released on three occasions in September and October in replicated trees in the station orchard resulted in a 42 and 38% HSW infestation in the treated and untreated trees, respectively.

The hickory shuckworm (HSW), *Cydia caryana* (Fitch), is considered by McQueen (1973) to be the most serious insect pest of pecan. Feeding by larvae in the shuck disrupts the flow of nutrients through the vascular system during the critical nut-filling period, causing poorly filled nuts, resulting in severe economic loss. Experiments were conducted with *Trichogramma minutum* Riley against the HSW from 1931 to 1935, but control was not achieved (Spencer et al. 1949). The present work was undertaken during 1989 to determine if *T. pretiosum* would parasitize HSW eggs in the laboratory and to determine if releases of *T. pretiosum* in an orchard situation would result in measurable differences in HSW infestation.

MATERIALS AND METHODS

T. pretiosum adults were isolated from the eggs of unidentified Lepidoptera, believed to be pecan bud moth, *Gretchena bolliana* (Slingerland), deposited on pecan seedlings at Byron, GA, during the spring of 1988. Successive generations of *T. pretiosum* were held in commercial colonization on Angoumois grain moth, *Sitotroga cerealella* (Oliver) eggs by Rincon-Vitova Insectaries (P.O. Box 95, Oak View, CA) until the tests began.

A black light trap mounted on top of a large cage was used to capture live HSW adults at Stoneville, MS. The cage was constructed of four wooden-framed screen doors (91.4 x 213.4 cm). A 22-watt circline black light which was level with the top of a funnel was mounted on top of the cage. The trap assembly was placed under a pecan tree in the test orchard.

The live trap was operated only when moths were needed, and was operated 8 nights from 9 September through 24 October 1989. A total of 709 male and 569 female moths were captured. These were placed in approximately equal numbers in 8 cages in the laboratory. Each cage measured 19.1 x 19.1 x 24.1 cm. The moths were provided with sugar water (5% w/v), supplied on cotton pads. Cages were misted with distilled water twice daily for the moths to drink. Cages were held under lab conditions of 22.2-26.7° C and 40-70% RH. Light was provided by overhead fluorescent lights during the day and a 125-watt incandescent bulb, reduced to 20% output by a rheostat, at night.

Twigs bearing 2-3 immature nuts were placed in water-filled 236 ml plastic cups, the lids of which had been slit to accommodate the stems. Nuts were placed in cages and HSW females were allowed to oviposit for 1-2 days. Nuts were then removed and placed in 1.9 l cardboard cartons which contained *Trichogramma* emerging from ca. 4200 parasitized *S. cerealella* eggs. Stems were inserted into small holes near the tops of the cartons, since *Trichogramma* are positively phototaxic and negatively geotaxic (Morrison 1985). Cartons were covered with the tops of 15.2 cm glass petri dishes onto which honey had been streaked with a very fine camel's hair brush. Nuts with HSW eggs were exposed to *Trichogramma* for one day, then removed to 236 ml plastic cups and held for parasite emergence. The centers of the lids had been cut out and the resulting rings used to secure 11 cm filter paper on the cups. This allowed ventilation to deter molding of the nuts, yet contained the minute *Trichogramma* adults. *Trichogramma pretiosum* had been previously identified to species by Dr. Gary Planter, University of California, Davis.

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The percentage of HSW eggs parasitized in the laboratory was determined daily by making estimates of the number of eggs on the nuts contained in each of the eight cups. Actual counts were made of dead *Trichogramma* which had hatched from the HSW eggs in each cup.

Field releases of *Trichogramma* were made by stapling flattened paper cups containing ca. 8,000 parasitized *S. cerealella* eggs to a tree. Two trees of each of five varieties received the treatment while two trees of the same varieties did not. Releases were made 26 September, 5 October and 11 October. *T. pretiosum* required about 8 days to develop to adults in *S. cerealla* eggs.

Twenty-nut samples were collected from each of the treated and untreated trees on 23 October. Nuts were placed in plastic cups and held for emergence of *Trichogramma*. Nuts were examined for evidence of HSW infestation on 31 October. A nut was considered to be infested if any of the following were found: Immature or mature larva(e), larval feeding damage (even if no larva was found), or adult exit hole. Data from the field test were subjected to analysis of variance to detect treatment difference.

RESULTS AND DISCUSSION

Although the majority of the HSW eggs on the nuts were visible, some were laid in crevices or on top of one another, which made it impossible to get an exact count. However, during a representative three day period, at least 1300 HSW eggs were counted, or a mean of 54.2/cup; correspondingly, 1427 dead *Trichogramma* were found in these same cups, or a mean of 59.1/cup. These counts, plus observations of blackened HSW eggs (which indicated parasitism) indicated that more than 90% of the HSW eggs were parasitized in the laboratory. This further confirms the wide host range of the genus *Trichogramma* shown by Morrison (1985).

In the field study, no emerged *Trichogramma* adults were found in the cups prior to removing the nuts to examine them for HSW larvae, nor were there any significant differences found between the number of nuts infested with HSW collected from trees treated with *T. pretiosum* and those from untreated trees ($f=0.24$, $df=1$, $p=0.63$). The number of infested nuts averaged 8.4 (SE $\pm$ 1.39) from the treated trees and 7.6 (SE $\pm$ 0.83) from the untreated trees. This converts to an infestation rate of 42% in the nuts from the treated trees and 38% from the untreated trees. The reason for this is not understood, but these results concur with those of Spencer et al. (1949) who found HSW infestation levels to be 3.1% higher in trees treated with *T. minutum* than in untreated trees.

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Table 1. x % nuts infested with HSW.

Variety	Treated[a]	Check[a]
Jackson	63	50
Choctaw	55	43
Cape Fear	53	30
Desirable	25	33
Caddo	15	35

[a]Represents mean of two replications, 20 nuts/replication.

PHYTOPHTHORA SHUCK AND KERNEL ROT

Michael W. Hotchkiss[1]

In 1988, shuck and kernel rot of pecan caused by *Phytophthora cactorum* (Lebert & Cohn) Schroeter occurred in south and central Georgia in well-managed, irrigated, mature (25 yrs. and older) pecan orchards but caused crop loss only in central Georgia. This was the first report of a *Phytophthora cactorum* pathogenic to pecan (Reilly et al. 1989).

The disease appeared in early September during a period when rainfall occurred on 11 of 15 d (Byron, GA, 28 August to 11 September) and was most severe in central Georgia in Peach, Crawford, Houston, and Bibb counties with estimated yield losses of up to 50% in a few orchards. In a mildly affected 'Schley' orchard where most infections occurred later in September yield losses were lower but effects on quality were higher (Reilly et al. 1990).

There did not appear to be cultivar (cv.) resistance to the disease as the disease was observed on 'Stuart', 'Schley', 'Desirable', 'Dependable', 'Davis', and 'Mahan'.

P. cactorum caused pecan fruit to rot starting at the attachment end and progressed distally to cover the entire shuck. The edge of the diseased area was light brown with a distinctive margin. The shucks turned dark brown to black but were moist and spongy. During prolonged moist periods, a whitish gray film of fungal mycelium developed over the rotted shuck tissue. The colonized area covered the circumference of the shuck and rapidly moved to the tip of the fruit often rotting fruit within 4 days. After two weeks the shuck dried and stuck tightly to the shell forming a "sticktight" which is a distinctive feature of the disease. In addition, pecan kernels colonized by the fungus had a dark brown to black seed coat and white mycelium and the endosperm often was gray and decomposed. These symptoms were for early September infections but later infections were observed up to shuck split and harvest.

The early infections resulted in a total loss of fruit whereas disease later in fruit development caused brown to black discoloration of the seed coat. These were difficult to separate from healthy nuts and resulted in reduced kernel quality and grade for entire field loads. Shucks of later infected fruit did not form stick tights as did the early infected fruit; instead they dried and split in a normal manner or else had a "tuliped" appearance. *P. cactorum* was easily isolated from infected pecan fruit and also isolated from soil in infected orchards (Reilly et al. 1990). Wounded or nonwounded pecan fruit inoculated with *P. cactorum* showed symptoms identical to naturally infected fruit (Reilly et al. 1989).

MATERIALS AND METHODS

The *P. cactorum* 'B-1' isolated from 'Schley' pecan at the USDA/ARS lab in Byron, GA was used in all tests. All inoculations were made with a water suspension containing 10,000 *P. cactorum* zoospores/ml.

To measure the effect of temperature on growth of *P. cactorum in vitro* 5 mm discs from the margin of a 7 d culture grown on Difco Lima Bean Agar were placed on Difco Cornmeal Agar plates (85-mm-dia.). Five plates were incubated at each of 7 temperatures (5, 10, 15, 20, 25,30 and 35°C) and the diameter of fungal growth was measured after 6 d.

To test cv. resistance, detached fruit clusters of ten pecan cvs. were misted with a suspension of *P. cactorum* and placed between moist paper towels in plastic tubs at 25°C. For an untreated control, clusters of all cvs. were sprayed with water and treated as above. The cvs. tested were 'Desirable', 'Stuart', 'Schley', 'Cape Fear', 'Sumner', 'Pawnee', 'Moneymaker', 'Moore', 'Elliott', and 'Van Deman'.

To test the ability of *P. cactorum* to infect pecan roots, barerooted 'Cherokee' seedlings (2 mos after germination) were placed in deionized water for 30 min. then planted in 15 cm square plastic pots containing Metromix 360 potting media. Other seedlings were put in deionized water containing *P. cactorum* in suspension and planted as before. A third group of plants were potted without any pretreatment but 15 ml of the same fungal suspension was applied as a drench to each pot. All plants were then held for 3 months

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on a greenhouse bench in a randomized complete block design with 3 treatments and 10 replications (pots). Plants were observed for symptoms on a weekly basis.

Leaf inoculations were conducted using six 'Cherokee' seedlings planted in Metromix 360 potting media in 12.5 cm clay pots. Three plants were sprayed with water and 3 plants were sprayed with a *P. cactorum* suspension. All plants were placed under glass tubes 45 cm high and 15-cm-dia. Resting on trays covered with water for an airtight seal. Plants were observed after 3 and 6 d.

RESULTS

The minimum and maximum temperatures for growth of *P. cactorum* from pecan were 10°C and 30°C respectively with an optimum temperature of 30°C (Figure 1). Detached fruit clusters of all ten cvs. rotted within 6 d when inoculated with *P. cactorum*, but fruit treated with water were still green and healthy. Potted pecan seedlings whose roots had been soaked in zoospore suspension or seedlings where *P. cactorum* was applied as a drench began showing symptoms of wilting and necrotic roots within 7 days. Within 3 months 10 of 20 plants inoculated with the fungus had died but all 10 control plants showed no disease symptoms. *P. cactorum* could be reisolated from roots of dead plants. All three seedlings whose leaves were sprayed with *P. cactorum* developed dark irregular lesions on leaves within 3 days. These lesions varied in size and were more severe on new foliage.

DISCUSSION

Phytophthora shuck and kernel rot caused by *P. cactorum* is a new disease of pecan capable of causing significant crop loss. This disease was observed only in Georgia but *P. cactorum* has been reported from other pecan producing states on apple, peach, pear, persian walnut and strawberry (Alfieti et al. 1984, Haygood et al. 1986, Blain 1931, Mircetich and Matheron 1983, Anonymous 1960). Reports of *P. cactorum* affecting strawberries show that rain is important in the dispersal and infection processes (Grove et al. 1985a, Grove et al. 1985b). Observations indicate that this may be true in pecan also.

The optimum and maximum temperatures for *P. cactorum* isolate B-1 are at least 30C and may be between 30 and 35°C. Temperatures observed during the 1988 epidemic (Byron, GA) were favorable for growth of *P. cactorum* with maximums between 20.5 and 32°C and minimums between 14.5 and 22°C. On only 5 d was the temperature above 30°C. This disease was not observed in the field in 1989 in central Georgia, when rain occurred on only 4 of 15 d from 28 August to 11 September and 11 d were above 30°C, and should not be a problem under hot or dry conditions. The lack of resistance to *P. cactorum* by all cvs. tested and observed reduces the chance that resistance would be found in the near future and means that established orchards are susceptible to infection. Resistance to *Phytophthora* spp. involved in root rot of Persian walnut is a top priority in walnut breeding programs. Partial resistance was obtained through interspecific hybrids and additional resistance is available from related genera (McGranahan 1987). Other *Carya* spp. could be a source of resistance to *P. cactorum* but their susceptibility is not known. Successful infection of pecan roots and leaves by *P. cactorum* are symptoms that have yet to be observed in the field. Root infection and fallen diseased shucks may play an important part in pathogen survival and overwintering. *P. cactorum* is an aggressive pathogen capable of rapid infection, reproduction and dispersal under optimum conditions. Orchards with a history of this disease should be monitored closely during periods of cool, wet weather. Shuck and kernel rot of pecan caused by *P. cactorum* is a disease which has occurred to a limited extent to date but could become very destructive if it becomes common and widespread throughout the pecan belt.

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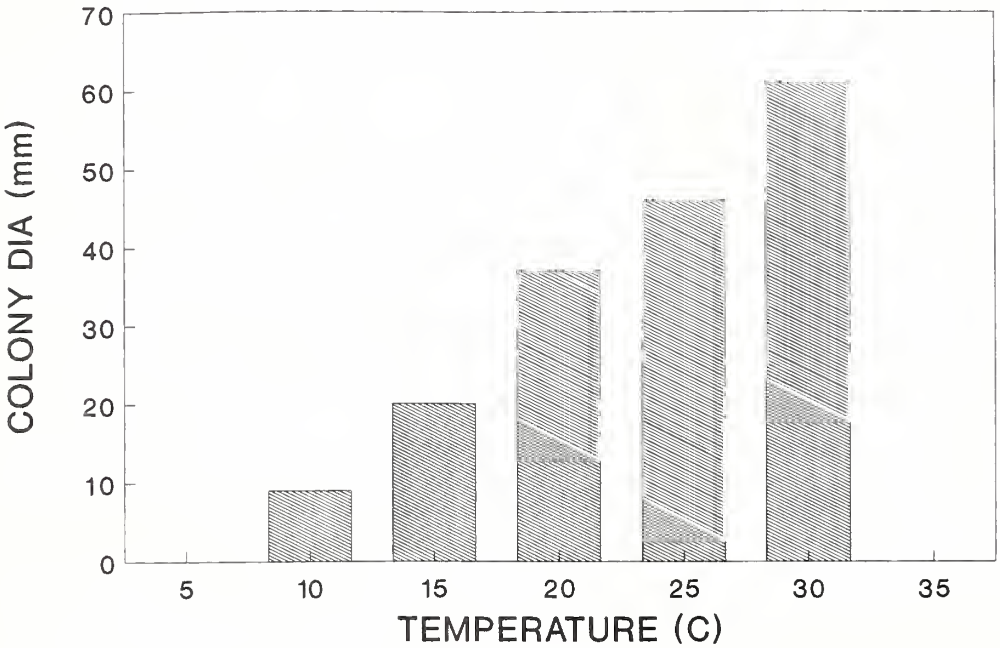

Figure 1. Effect of temperature on growth of *P. cactorum* (isolate, B-1 from pecan) on cornmeal agar.

PECAN SCAB: A REVIEW AND CONTROL STRATEGIES

A.J. Latham[1] and W.D. Goff[1]

ABSTRACT

Free moisture on plant tissues is required for infection by *Cladosporium caryigenum*, the causal agent of pecan scab. The intensity of scab development is related to cultivar susceptibility and rainfall frequency, with lesion numbers increasing to epidemic proportions under prolonged wet weather. Many strains of *C. caryigenum* exist in most pecan growing areas and adapt to previously resistant cultivars because of the genetic diversity of pecan and the adaptability of the fungus. Consequently, growers have been forced to rely on fungicides for control of scab on most commercial cultivars in areas receiving high amounts of rainfall.

Successful production of quality pecans in humid areas of the southeastern United States depends on control of scab, caused by *Cladosporium caryigenum* (Ell. et Lang.) Gottwald. Scab is the major disease that occurs on developing nut-shucks (Demaree 1924, Gottwald 1985, Latham 1982, Payne et al. 1979). Severely infected nuts may drop prematurely or kernels may not develop even though the nuts remain attached to the branches (Gottwald 1985, Latham 1982, Latham et al. 1972). Generally, fungicide application schedules focus on scab control, with control of other pecan diseases as a secondary benefit (Latham 1970). The magnitude of disease control programs may be illustrated by the amount of fungicides used. Littrell and Bertrand (1981) stated: "The annual use of fungicides on more than 3 million trees in the coastal plain production area (including portions of North Carolina through eastern Texas), places pecan as the third largest market for fungicides in the United States, following peanuts and deciduous fruits."

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SYMPTOMS

Pecan tissue is most susceptible to scab when it is young and actively growing. Leaves become less susceptible after they change from the light yellowish-green character of young leaves to the later deep green color of mature leaves (Demaree 1924). Scab on new foliage appears as olive-brown, velvety lesions on both dorsal and ventral leaf laminae and veins. Initially, the lesions are pinpoint in size, but they may enlarge and coalesce. On highly susceptible cultivars, small gray, fleck-like, circular lesions may extend over part or all of the leaf laminae, aggregating into a solid leaden-gray smudge on the underside of some leaflets. Lesions on shucks are small, black, circular, and appear sunken as the nut-shuck enlarges. Entire shuck surfaces may become blackened by coalesced scab lesions on susceptible cultivars. Immature scabby nuts in such condition fall prematurely before harvest or fail to fill. Lesions may develop on current-season leaf petioles and twigs resulting in blights that cause the death of shoot terminals (Latham 1876, Latham et al. 1972, Payne et al. 1979).

CAUSAL ORGANISM

Scab is caused by the fungus *Cladosporium caryigenum* (Ell. et Lang.) Gottwald (Syn. *Fusicladium effusum*) (Gottwald 1982). Davis and Graves (1970) studied growth of the fungus on Czapek's solution agar amended with vitamins in various combinations. They showed that it grew very slowly, developing colonies 11-22 mm in diameter after 17 days incubation at 24°C. Sporulation was induced by light and growth was best on oatmeal agar.

DISEASE CYCLE AND EPIDEMIOLOGY

The scab fungus overwinters as stromata on shucks, twigs, bud scales, and leaf rachises, or petioles of pecan. In the spring, under conditions of frequent rains and high relative humidity, the stromata produce conidia that function as primary inoculum. Leaves of susceptible cultivars may be infected within 2-3 hr when there is free water on the plant tissues. Latham and Rushing (1988) reported maximum infection occurred after 36 hr of continuous leaf wetness. Temperature did not affect the number of lesions produced at 10, 15, 20 and 35°C in all leaf wetness periods up to 48 hr (Gottwald 1985); however, maximum lesion production occurred after 32-48 hr of wetness at 20°C and 48 hr of wetness at 25°C. Pecan scab

lesions first become noticeable by production of conidia 7-9 days after inoculation (Gottwald 1985, Latham 1982, Latham and Rushing 1988).

Susceptibility of pecan foliage decreases rapidly with age. Leaves are most susceptible approximately 7-21 days after bud break (Gottwald 1984, Gottwald 1985). Leaves from the initial growth flush lose susceptibility, but a second flush of new leaves in mid-summer on older trees results in more susceptible juvenile leaves. Young nonbearing trees may have several flushes of growth through the season and may therefore have an extended period of time when some foliage is susceptible.

When scab epidemics occur, all leaves may fall from the tree during the summer (Latham 1982). Worley (Worley 1979) found when pecan trees refoliated during August, carbohydrate reserves were restored by December, but the following year's crop was either reduced or a total failure. Also, defoliation of trees that occurred during September caused the greatest depletion of carbohydrate reserves and prevented pistillate or staminate flower production the next year. Consequently, the lack of flower production resulted in a total crop failure.

While a great deal of valuable epidemiological information is available regarding the foliar phase of the scab disease (Gottwald 1985, Gottwald and Bertrand 1983, Latham 1982, Latham and Rushing 1988), relatively little is known about the effects of *C. caryigenum* and other fungi on nut infection and development. The major effect of pecan scab on nut quality results from infections occurring prior to mid-June, coincident with the time of shell (endocarp) differentiation (Gottwald and Bertrand 1983). The pecan fruit of most commercial cultivars remains susceptible to *C. caryigenum* throughout the nearly 6-month growing season (Demaree 1924). Thus, secondary cycles of infection may increase inoculum density enormously (Latham 1982). On trees not protected with season-long fungicide applications, part of the nut-shuck may become black from the coalescence of scab lesions and fall from the tree prematurely during July and August (Hunter 1983, Latham 1982, Payne et al. 1979). Nuts remaining on untreated trees are usually of very poor quality, i.e., kernels do not develop; consequently, the commercial value of the nuts is severely reduced.

HOST-PARASITE RELATIONS

Several pathologic races of *C. caryigenum* occur on pecan. Converse (1960) identified four races from the western cultivars Burkett, Sovereign, Squirrel, and Western. He also demonstrated that isolates from the eastern pecan cultivars Mahan, Moneymaker, Schley, and Success were pathogenic only on their original hosts. Earlier, Demaree and Cole (1929) found increased pathogenicity occurred on the Delmas cultivar with each reinoculation, indicating that *C. caryigenum* may adapt to new cultivars or develop new races. Gottwald (1989) tabulated the loss of resistance of commercial cultivars of pecan (Table 1). His data show that when previously resistant cultivars are planted in large enough acreages, they often become susceptible to scab. During 1961, for the first time, many pecan growers in south Alabama observed scab on the cultivar Stuart, which was considered scab resistant in some pecan growing areas (Diener 1962). Subsequently, a scab epidemic occurred on Stuart throughout the area during 1966 (Diener and Garrett 1967). Infection of old pecan cultivars by *C. caryigenum* and adaptation to newer cultivars (Gottwald 1989, Hunter 1983) have forced growers to rely on fungicides to control scab in areas that receive high amounts of rainfall. The current susceptibility of pecan cultivars recommended for planting in the Southeast has been reported by Thompson (1989).

CONTROL

Making complete plans for installation of a pecan orchard are some of the most important disease control considerations a grower can make. Once the grower has planted his trees, he has to live with what he has done. Therefore, what should the grower consider when establishing a new pecan orchard?

1. The primary consideration should be given to site selection. Is the soil appropriate to support vigorous growth of trees?

2. The orchard should be designed so that prevailing breezes may readily flow through it. When foliage and nuts dry quickly, i.e., within an hour or two, the probability of infection and disease development is greatly diminished.

3. Selection of appropriate cultivars with at least moderate scab resistance (Thompson 1989) is extremely important. Although strains of *C. caryigenum* may develop and attack a previously resistant cultivar, most cultivars retain a degree of resistance that is of practical value to growers. Diseases flourish in a monoculture once the pathogen has adapted to the particular host plant. Therefore, a grower should plant several cultivars to maximize genetic diversity in the orchard.

4. Tree spacing that allows good airflow and utilizes sunlight to the maximum promotes good tree growth. Proper tree spacing also facilitates drying of foliage and nuts following heavy dews and rainfall.

5. Proper maintenance of the orchard floor by close mowing of ground cover will reduce the high humidity associated with lush growth of vegetation under trees.

6. Application of supplemental irrigation water through a drip procedure is highly desirable. Applying water to pecan foliage and nuts through sprinklers is an open invitation for development of an intolerable scab problem (conidia of *C. caryigenum* + water = scab!). However, there is need for research on application of fungicides via overhead sprinklers (fungigation), which feasibly could reduce sporulation from inoculum sources on the orchard floor as well as provide protection on wetted leaves.

In order to effectively evaluate the efficacy of fungicides, pathologists often use pecan cultivars that are highly susceptible to scab. But, we must always emphasize to growers that such cultivars may not be advisable for them to plant (Latham 1982), and that spray recommendations based on such research may be overly stringent for resistant cultivars (Thompson 1989). Recent research showed that scab incidence on unsprayed Cheyenne, Cape Fear, and Cherokee trees was 36.4, 67.0, and 100%, respectively (Latham et al. 1988). Nut-shucks on all of the cultivars were covered with scab lesions and many nuts were already on the ground when data were taken at the end of August (Latham et al. 1988). These data indicate the level of losses that could be sustained when these cultivars are grown in the southeastern part of the U.S. and not sprayed with fungicides.

Propiconazole (Orbit) has been tested for after-infection control of *C. caryigenum* in pecan leaves in the greenhouse (Latham and Hammond 1983). The curative activity of this ergosterol biosynthesis inhibitor fungicide was absolute when treatment was made within 2 days of inoculation. When application was delayed until 4 days after inoculation leaf-flecks developed. These flecks apparently were infected leaf cells killed by the systemic activity of propiconazole. Subsequent studies showed that 3% of *C. caryigenum* leaf infections survived 6 days and 23% survived 8 days after propiconazole treatment (Latham and Hammond 1983). Preliminary field testing of after-infection control of pecan scab with propiconazole has been conducted (Latham and Burgess 1984). Propiconazole at 0.585 l/ha was applied at the start of the control schedule then again after a 21-day interval plus 48 hr or 96 hr following a 6-hr leaf wetness infection period. In September, the average incidence of clean nut-shucks from propiconazole applications 48 or 96 hr after the leaf wetness infection period was 96.2 and 60.4% respectively, and 0% from unsprayed trees.

Typically, pecan scab has been controlled with applications of triphenyltin hydroxide (TPTH, Du-Ter, and SuperTin) made at bud break followed by three applications at 14-day intervals or through the pollination period (Gazaway et al. 1989). Subsequently, applications have been extended to 21-day intervals with applications made until the end of August. When intermittent to continuous rainy weather occurs, it is advisable to close the applications to approximately 10-day intervals.

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Table 1. Loss Of Resistance Of Pecan Cultivars To Pecan Scab Between 1910 and 1956.

Variety	1910	1920	1931	1940	1954	1956
Georgia Giant	S	S	S	S	S	S
San Saba	S	S	S	S	S	S
Delmas	R	S	S	S	S	S
Van Deman	R	S	S	S	S	S
Schley	R	S	S	S	S	S
Pabst	R	S	S	S	S	S
Alley	R	R	S	S	S	S
Mobile	R	R	S	S	S	S
Moore	R	R	S	S	S	S
Success	R	R	S	S	S	S
Teche	VR	VR	R	S	S	S
Frotscher	VR	VR	R	S	S	S
Moneymaker	VR	VR	R	R	S	S
Curtis	VR	VR	VR	VR	VR	S
Stuart	VR	VR	VR	VR	VR	S

S = Susceptible; heavy losses from pecan scab common in some locations.
R = Resistant; occasional light losses from pecan scab in a few locations.
VR = Very resistant; losses from pecan scab very rare.

PECAN ANTHRACNOSE: REOCCURRENCE OF AN OLD PROBLEM

T.B. Brenneman[1]

ABSTRACT

Anthracnose of pecan *[Carya illinoinensis* (Wangenh.) C. Koch] caused by *Glomerella cingulata* (Ston.) Spauld. and Schrenk was first reported in the United States in 1914 (Rand 1914). Although widespread, it was not reported to cause substantial damage, and the disease received little attention during the next 75 years. Recent outbreaks in Georgia have demonstrated that the pathogen can cause significant late season yield loss on some varieties. Although originally reported on both shucks and leaves, recent observations have indicated only shuck symptoms which consist of sunken, black lesions usually initiated near the proximal end of the shuck. The fungus can penetrate the shell and kernel resulting in decreased kernel size, abortion of the nut, or shucks clinging to the shell at maturity. Symptoms were readily reproduced by inoculating detached nut clusters in the lab, but results of field inoculations were more erratic. *G. cingulata* and its anamorph, *Colletotrichum gloeosporioides* (Penz.) Sacc., are known pathogens of ripening and senescing tissues and are often associated with long latent periods. The frequency of isolation from shuck tissues increases steadily throughout the summer on susceptible cultivars and sometimes reaches 100% by late season. However, growth can also be saprophytic and successful isolations can be made from shucks with a variety of symptoms late in the season. More work is needed to determine the role of *G. cingulata* on different varieties and clarify the etiology of this and other shuck necroses.

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In 1911, Rand (Rand 1911) described a pecan leaf-blotch which he attributed to *Mycosphaerella convexula* (Schwein. Thüm, Sacc.). He described specimens obtained from Alabama, Georgia, Florida, South Carolina and Ohio. In 1914, Rand (Rand 1914) published a more extensive work in which the causal organism was positively identified as *Glomerella cingulata*. He described the anamorph, now known to be *Colletotrichum gloeosporioides* Penz., and indicated that it was found more frequently than the teleomorph, although many strains were holomorphic. Rand (Rand 1914) described in detail the symptoms observed on leaves and nuts of both natural infections and those resulting from inoculations in the laboratory. He reported that symptoms did not occur until mid to late season. Pecan isolates of *G. cingulata* were found to also cause bitter-rot symptoms on apples (Rand 1914).

After this extensive initial work by Rand, little attention was focused on this problem. It was mentioned in some subsequent pecan production summaries such as that of Stuckey and Kyle in 1925. They reported that "Anthracnose is well distributed throughout most localities..., attacks have been light and the industry has not suffered any serious effects from the disease" (Stuckey and Kyle 1925).

The disease faded even further into obscurity and was pretty much forgotten until recent years when pecan growers in Georgia started experiencing problems with shuck necrosis late in the growing season. Symptoms unrelated to scab were linked to a high incidence of *G. cingulata* on diseases tissues. This was documented by Brenneman and Reilly (1989) who successfully reproduced the symptoms by inoculating detached nut clusters in the laboratory. They also reported that the fungus could penetrate the shell and rot the kernel as well as infect the shuck to cause "stick-tights." Cultivars reported to be most susceptible based on field observations were Wichita, Grabohl, Van Deman and Schley (Brenneman and Reilly 1989).

Unfortunately the etiology of this disease is confounded by several factors. First, there are a number of shuck disorders reported on pecan. Stein and McEachern (1983) discussed several of these as well as possible causes including pathogens, irrigation, nutrition and physiological factors. For example, shuck dieback is a condition commonly affecting the variety Success and Success hybrids. This "shuck disease" as originally described by Schaller et al. (1968) begins with a black spot on the shuck adjacent to

the stem, similar to the symptoms later reported with *G. cingulata* (Brenneman and Reilly 1989). Shuck disease later withers the apex end and may envelop the entire shuck. It is thought to be caused by abiotic factors (Herrera 1982, Schaller et al. 1968) and the potential damage caused by this condition was documented by Schaller (1971).

Pecan stem end blight has been described by Halliwell and Johnson (Halliwell and Johnson 1978 and is reported to be of biotic origin and thus controlled by the use of fungicides. The suspected pathogen is *Botryosphaeria* sp. (Halliwell and Johnson 1978) and the nut-rotting potential of *B. ribis* has been demonstrated in India (Saharan 1974). A variety of symptoms were reported including severely rotted nuts, shucks fusing with shells, and simple colonization of shucks only. To further complicate the issue, a disease known simply as "dieback" affecting only twigs and limbs has been attributed to *Botryosphaeria berengeriana* DeNot (Marz 1918).

The second factor confounding the etiology of shuck diseases is the occurrence of both obvious and inconspicuous nut splitting problems. Worley and Taylor (15) reported this in 1972 and subsequent work by Daniell and Prussia (2) demonstrated the relationship between these symptoms and high osmotic pressures reached within the developing nuts of some varieties. Of interest to this discussion is the fact that affected nuts may exhibit obvious longitudinal splits or only minor cracks that result in a discolored spot on the shuck. Also, the variety found to be most susceptible to this split, Wichita, is also one of the most likely to exhibit symptoms of infection by *G. cingulata*.

Research conducted during 1989 demonstrated that *G. cingulata* can cause a significant reduction in yield and quality of pecan cv. Wichita, even when symptoms develop very late in the season (T.B. Brenneman, C.C. Reilly and M.W. Hotchkiss, unpublished data). Approximately 30% of individual nuts showing some symptoms (<25% of shuck discolored) had progressed to more than 75% discoloration at harvest two weeks later. There were 98.5 nuts/lb in this category versus 87.0 nuts/lb where there was still <25% necrosis at harvest. Those with no disease had 75.8 nuts/lb.

This study also demonstrated that higher severities of anthracnose are correlated with higher rates of late season nut drop. Unseasonal fruit drop occurs in most dicotyledonous tree crops and has been associated with *Colletotrichum* spp. in some of those (Wellman 1972). It is also of interest to note that Rand (Rand 1914) reported an association between pecan anthracnose and nut drop in his initial studies on the disease.

Isolation studies have demonstrated that the incidence of *G. cingulata* isolations from pecan shucks rises steadily through the season and may reach 100% in some orchards (C.C. Reilly, T.B. Brenneman and M.W. Hotchkiss, unpublished). This occurs even before visual symptoms are apparent on the shucks. This symptomless colonization indicates that latent infections are involved, something that occurs frequently with *Colletotrichum* spp. (Wellman 1972). Usually these infections are not evident until triggered by a change in the physiological state of the maturing host tissue. This appears to be true for pecan as well.

This process of latent infection along with the possibility of systemic infections via the branches adds to the confusion of determining etiology. Isolation studies from specimens collected throughout Georgia have often found *G. cingulata* associated with a variety of shuck necrosis symptoms, but it also appears to be an excellent saprophyte. Excellent growth occurs on shuck tissues damaged by other causes such as physiological split described previously.

Our biggest challenge currently is to determine the etiology of the various shuck necrosis problems found on a number of pecan varieties throughout the state. Disease ratings taken near harvest in 1989 indicated definite differences among varieties with regards to symptoms (T.B. Brenneman, unpublished). Results are given in Table 1, and those with basal symptoms known to be associated with *G. cingulata* infection are listed separately from those with shuck dieback as typified by "Success." It is apparent that there are different shuck necrosis symptoms and that varieties differ significantly in susceptibility to them. For example, most varieties exhibited no symptoms of *G. cingulata* infection whereas Wichita had more than 50% of the clusters affected.

The role of other factors such as nutrition, irrigation, other pathogens, etc. needs to be elucidated. However, we also need to learn more about the biology of *G. cingulata* in pecan orchards. Then, where the fungus is involved, we will have a basis to formulate control strategies, and where it is not involved, alternate programs can be developed.

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Table 1. Occurrence of shuck necrosis on various pecan varieties, Tifton, GA (Oct. 3, 1989).

Variety	# Clusters w/*Glomerella*[1]/ # Clusters evaluated	% w/*Glomerella* symptoms	% w/tip dieback
Stuart	0/20	0	0
Money maker	1/20	5.0	20
Schley	2/20	10.0	0
Van Deman	8/46	17.4	0
Kiowa	0/20	0	0
Frotcher	0/20	0	0
Alley	0/20	0	0
Curtis	0/30	0	0
Summers	2/21	9.5	0
Moore	0/22	0	4.5
Pabst	0/22	0	4.5
Mobile	0/27	0	0
Ivey	0/30	0	0
Woodard	0/32	0	0
Desirable	0/31	0	0
Farley	0/22	0	0
Tejas	0/30	0	6.7
Big Z	0/20	0	0
Bradley	0/20	0	0
Tesche	0/28	0	0
Melrose	0/20	0	0
Mahan	0/30	0	10
	Note - 11 additional Mahan clusters died at about 1/2 of full size development from unknown causes.		
Burkett	0/32	0	0
Williamson	0/30	0	6.7
W. Schley	2/31	6.5	25.8
Brooks	1/33	3.0	6.1
Oklahoma	0/36	0	0
Wichita	26/47	55.3	0
Penn Cluster	0/30	0	0
French TW	0/30	0	3.3
Harris	0/35	0	0
Hasting	0/33	0	0
Barton	0/30	0	56.7
Cape Fear	0/33	0	0

[1]Clusters with ≥1 nut exhibiting lesions similar to those known to be associated with *G. cingulata*.

ZONATE LEAF SPOT OF PECAN: A REVIEW AND RESEARCH NEEDED

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ABSTRACT

Defoliation of pecan trees by zonate leaf spot during years of above normal rainfall has often occurred in trees located adjacent to woodlands. Most of our knowledge of this disease is based upon a secondary cycle of infection involving cone-shaped macroconidia produced by *Cristulariella moricola*. Sclerotia collected and overwintered outdoors and in the laboratory have shown development of fruiting structures of the sexual stage, *Grovesinia pyramidalis*. However, the epidemiology of primary infection has not been determined. Thus, our information is inadequate to prescribe fungicides to control this disease.

Cristulariella moricola (Hino) Redhead (=*C. pyramidalis* Waterman & Marshall), the causal agent of zonate leaf spot of pecan, can cause severe defoliation of pecan trees (Latham 1969, Latham 1972). The disease is most severe on pecan foliage in the Southeastern United States during the July through September rainy season, but is absent during dry seasons. Zonate leaf spot has occurred in orchards maintained on a scab prevention schedule using dodine or triphenyltin hydroxide. Benomyl has been recommended for control of zonate leaf spot in Georgia, but the development of resistance by many fungi to benomyl (Littrell 1974, Littrell 1975) suggests that *C. moricola* might also develop resistance to this fungicide.

Evaluations of fungicides for control of zonate leaf spot have been conducted in orchards with a history of the disease, but tests generally have not been successful due to its sporadic occurrence (Latham 1969). In recent greenhouse tests, propiconazole was found to be effective in stopping growth of *C. moricola* in established lesions, thus effecting a cure of zonate leaf spot.

SYMPTOMS

The zonate leaf spots on the dorsal side of pecan leaves were grayish brown in color, with concentric ring formation less distinct than from the ventral view (Latham 1969). Leaf spots viewed from the ventral side appeared light brown to tan in the center, becoming darker brown toward the periphery. Small lesions were typically circular. A series of concentric rings occurred in leaf spots of larger irregular-shaped necrotic tissues, resulting in the zonate appearance. A film of crystalline-like material formed over the leaf spot surfaces, giving them a gray-brown to gray-white appearance depending upon the angle of incident light. The crystalline material on the ventral leaf surface was lumpy near the center of the zonate lesions. Leaves with extensive lesion development appeared dried, and curled upward from the margins, before falling from the trees (Latham 1969). Defoliation of infected foliage was pronounced in mid-September.

CAUSAL ORGANISM

The leaf spot pathogen, *Cristulariella moricola* (Hino) Redhead (Syn. *C. pyramidalis* Waterman & Marshall), is anascomycete: teleomorph *Grovesinia pyramidalis* M. Cline, Crane, S. Cline (Cline 1983). However, little is known about the sexual stage of this pathogen and its ecology.

Black sclerotia, 2-5 mm in diameter, of *C. moricola* have been produced on both naturally infected leaves and on artificial media. Sclerotia are formed within 3 days on media supplemented with yeast extract or V-8 juice and within 4 days on potato dextrose agar. The occurrence of sclerotia and their longevity appear to be correlated with nutrition and moisture composition of the growth substrate (Latham 1969, Latham 1974, Latham 1987).
A discomycete with cup-shaped apothecia 1.5-2.0 mm in diameter has been produced on sclerotia. Mycelial cultures have been developed from ascospores (Cline 1983, Harada et al. 1981).

Examination of *C. moricola*-infected pecan leaves from the orchard may reveal cone- or pyramidal-shaped fruiting structures (macroconidia) attached to the zonate lesions (fruiting structure=pyramidal head *sensu* Waterman and Marshall (Waterman, 1947). Fruiting structures develop from diseased tissues with a

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fertile hyphae 0.5-1.0 mm long topped by a pyramidal head 157-568 µm long and 80-210 µm in diameter (Latham 1969). Macronidia are scarcely detectable macroscopitally, but may be observed with a hand lens or other means of low power magnification. Macroconidia were not observed on small lesions (7-10 mm); however, on large lesions (15-20 mm), erect macroconidia were distributed randomly over the leaf spot.

Macroconidia cultured on greenhouse-grown pecan leaves were used in *in vitro* studies with Czapek-Dox plus yeast extract agar (Latham 1974). Plates were inoculated with macroconidia and incubated at temperatures ranging from 6 to 30°C and at 3°C intervals. The optimal temperature for growth of *C. moricola* was 21°C, with colony diameters approaching 45 mm within 96 hr. Additionally, *C. moricola* has been cultured on agar plates amended with a variety of carbohydrates, vitamins, and natural substrates, but macroconidia did not develop.

The production of microconidia *in vitro* has been reported by several investigators (Latham 1969, Niedbalski et al. 1979, Waterman and Marshall 1947, Yokoyama and Tubaki 1974), but their infectivity has not been demonstrated. Cline et al. (1983) used microconidia to fertilize sclerotia and produce apothecia and ascospores.

Trolinger et al. (1978) reported *C. moricola* occurred on both woody and annual plants, including 73 species in 36 families distributed in the Central and Eastern United States.

DISEASE CYCLE

Until now, many thought sclerotia, formed on naturally infected, defoliated leaves of several hosts, were the overwintering stage for *C. moricola* (Cline 1983, Davis 1962, Harada et al. 1981). Harada et al. (1981) collected sclerotia in November, overwintered them outdoors and observed apothecia on them in May and June, 1981. They were unable to obtain infection with ascospores. However, they did obtain infection of Japanese apricot using hymenial fragments from the apothecium and mycelia from an ascospore-isolated culture. Cline et al. (1983) succeeded in producing apothecia on sclerotia incubated 6 months in the dark at 4°C followed by 4 weeks incubation at 15°C in the light. However, they were unable to collect ascospores in sufficient numbers to conduct pathogenicity studies.

Epiphytotics have been associated with one pyramidal-shaped conidium typically found in the center of all lesions on pecan leaves (Latham 1969, Niedbalski et al. 1979).

Tests were conducted using lesions dried for 16 and 60 days. The lesions were thoroughly rewetted and maintained in a water-saturated atmosphere. After 96 hr, lesions dried 16 and 60 days produced macroconidia over 49 and 35% of the lesions, respectively (Latham 1974).

EPIDEMIOLOGY

Macroconidia were used to study the epidemiology of zonate leaf spot and the development of secondary cycles of infection (Latham 1974). Investigations were made on potted seedling pecans, inoculated with macroconidia of *C. moricola* and incubated at constant temperatures. Maximal lesion diameters and macroconidial numbers occurred at 21°C; largest lesions developed at temperatures between 18 and 21°C. The fungus grew quite rapidly with lesions of 3.2, 6.9, 11.0, and 15.3 mm developing in 48, 72, 96, and 120 hr, respectively, at 21°C.

Relative humidity (RH) was a significant factor in development of lesions and macroconidia production (Latham 1974). At 97 to 100% RH, macroconidia were produced abundantly as long as lesions were wet and enlarging. When RH was reduced to 87%, macroconidia did not develop.

Tests were conducted *in vitro* to develop methods for production of macroconidia for use in epidemiology research. These investigations showed that 360 macroconidia per petri dish were produced on autoclaved pecan leaves in a water-saturated atmosphere. However, when an excess of water was present in the dishes, sclerotia were produced accompanied by reduced numbers of macroconidia (Latham 1974). Also, light was required for production of macroconidia on the sterile leaf substrates (Latham 1987).

CONTROL

Since sclerotia have been found on diseased leaves, a promising method for control of zonate leaf spot might be the raking and burning of leaves.

We do not know when to start the application of fungicides to prevent infections because environmental conditions for maturation of ascospores and their method of dissemination are unknown.

Benomyl fungicide has been recommended for control of zonate leaf spot of pecan (Ellis et al. 1981). Regular spraying with dodine and triphenyltin hydroxide (TPTH) has not controlled *C. moricola*. In fact, zonate leaf spot was discovered in orchards sprayed with dodine and TPTH (Latham 1972).

Propiconazole protected mature pecan leaves in the greenhouse for over 6 weeks. It was also effective in stopping the growth of *C. moricola* in established lesions, thus effecting a cure of zonate leaf spot of pecan (Latham 1987). When rainy weather occurs during midsummer in an orchard with a history of zonate leafspot, applications of Orbit would be advised (Davis 1962, Latham 1972, Latham 1987). When the weather is dry, fungicidal controls would not be needed, since this disease usually has been a problem only in association with abundant rainfall.

None of the presently available varieties of pecan are resistant to zonate leaf spot.

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THE CHALLENGES AND PROSPECTS FOR DEVELOPING PECAN CULTIVARS WITH LASTING RESISTANCE TO CROP-LIMITING DISEASES

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ABSTRACT

Disease control comprises a major part of pecan production costs. Resistant cultivars would greatly benefit the industry. Personal observations suggest that quality resistance to many foliar diseases of pecan may be achieved through simple selection processes. Developing resistance to scab, the most serious disease, however, is a more complex problem. Considerable progress has been made in recent years in defining factors associated with scab resistance. Techniques have been devised to facilitate quantitation of these factors. Utilizing these new research findings and techniques, progress is now being achieved toward identification of sources of quality resistance for breeding purposes. Procedures for transfer of quality resistance genes to acceptable pecan types are now available. Development of cultivars with lasting resistance within the near future is now a distinct possibility.

Diseases are limiting factors in pecan (*Carya illinoensis* Koch) culture in the humid southeastern states. Leaf diseases may at times cause complete early defoliation of some cultivars, and often severely limit functional tree leaf area during the growing season. Maintenance of healthy foliage is known to be very important for tree vigor, nut quality, and fruit set on an annual basis. The most significant disease of pecan, however, is scab caused by *Cladosporium caryigenum* (Ell et Lang) Gottwald which most severely affects nut production. Scab may also be prominent on leaves and stems. Under some conditions this disease may cause total crop loss. It exacts a severe penalty every year, if not in crop loss, in the cost of necessary protection measures in most areas of the southeast pecan region.

Control of pecan diseases requires at least seven to eight fungicide applications per season at considerable expense. Concerns over environmental influences of pesticides and constraints caused by increased regulatory activities of the Environmental Protection Agency may severely limit use of fungicides in the future. Further, the failure of commodity prices to keep pace with production costs in recent years has created another serious problem for pecan producers. Disease resistant cultivars would be a decided asset for the pecan industry. We feel that disease resistance is an absolute necessity if pecan production in the humid southeast is to continue to compete. Perhaps most important, following many years of observation and concentrated research into various aspects of scab disease resistance, we are convinced that lasting disease resistant cultivars are attainable, and with concentrated continued research effort, this can be achieved within the next few years. Historically breeding for resistance to disease, with any tree crop, is time-consuming and costly. Thus, initiation of a program with such a goal must be carefully planned, documented with basic research findings, and must employ the latest available plant breeding technologies. We feel that we now have the knowledge, techniques, and plans that will permit significant and immediate progress.

BREEDING FOR SCAB RESISTANCE

Areas of notable research progress in breeding for scab resistance have been centered around several immediate goals, namely: (1) basic understandings of the scab pathogen, variability in nature, adaptive capability, and epidemiology; (2) definition of factors associated with resistance; (3) identification of quality sources of resistance genes; and (4) development of procedures to expedite the incorporation of these resistance genes into horticulturally desirable cultivars.

VARIABILITY AND ADAPTIVE CAPABILITY OF CLADOSPORIUM CARYIGENUM

The scab fungus is known to have great genetic diversity in nature and an operative mechanism for adaptive genetic reconstitution (Alford 1970, Soonthornpoct 1973). There has been a historical pattern of selection and naming of pecan

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cultivars, thought to be resistant to scab, but which, upon mass (commercial) propagation and distribution, have eventually been found to be susceptible to scab. This suggests that there is considerable genetic diversity of the pathogen in nature. KenKnight (KenKnight 1968), using scab inoculum from several sources, demonstrated infection on previously "non-scabbing" cultivars in Louisiana. Street (Street 1972), using a technique devised by McNeill (McNeil and Graves 1970) amenable to quarantine necessities, screened excised nuts of 25 pecan cultivars against 27 isolates of *C. caryigenum*. All cultivars except Baker were significantly infected by one or more of the isolates, and minor infection occurred upon Baker.

Although no true sex stage has been associated with *C. caryigenum*, mechanisms that could account for observed genetic variability and adaptability have been observed. Anastomosing of hyphae, fusion of spores, fusion of newly formed spores with hyphal strands, all of which could play a role in heterokaryosis or parasexual behavior have been observed (Blasingame 1968). Microconidia are produced, in some instances in great profusion, that may function as spermatia in sexual behavior patterns (Blasingame 1968). Somatic hyphae are largely uninucleate, but binucleate hyphae are common. Conidiophores and conidia are multinucleate (Blasingame 1968, Soonthornpoct 1973). Occurrence of genetic recombination can be easily demonstrated in the laboratory employing hyphal-tip or single spore isolates, hyphal-tip or single sporing methods and identifiable cultural markers such as growth rate on standard and minimal media, hyphal and mycelial characteristics, etc. (Alford 1970, Soonthornpoct 1973).

PATHOGENICITY EVALUATIONS

Pathogenicity screening of pecan genotypes for resistance to *C. caryigenum* has posed problems (Graves et al. 1979, McNeill and Graves 1970). First, any screening effort must obviously employ a wide range of isolates representative of the genetic diversity throughout the pecan belt, thus necessitating procedures amenable to quarantine requirements. Secondly, resistance in leaf and nut tissues cannot be correlated, thus screening of seedling foliage, only, is of questionable value. Testing of progeny by plantation throughout the pecan region can be prohibitively expensive, and can at best provide doubtfully adequate exposure in light of obvious genetic diversity and adaptive capability of the pathogen. A thorough understanding of resistance phenomena could provide for the most effective and efficient screening method.

EPIDEMIOLOGY, OCCURRENCE OF SCAB AMONG HICKORIES

Early reports of scab disease have shown that it is not uniformly distributed and does not attack the same pecan cultivars to an equal extent in all locations. The spread of the disease on one cultivar appears to be independent of that on others (personal observation). Buildup of the disease in new plantings has always proceeded slowly, many times requiring years to reach significant levels, and buildup rate has seemingly proceeded independently for each cultivar. The buildup rate in relation to cultivar, however, may differ according to location, suggestive of fungal genotypic variability according to location. There are many native pecans (distinctive genotypes) that do not exhibit scab infection in nature, even though they are located amidst an abundance of "scabbing" trees. Experience suggests that this occurrence is simply related to extent of exposure, i.e., once "non-scabbing" trees are vegetatively propagated, and scattered over the humid Southeastern United States, fungal genotypes capable of parasitizing them will slowly increase. When considering the adaptive capability of the scab fungus, and the range of fungal genotypes apparently present across the pecan belt, the presence of quality, lasting resistance within *C. illinoensis* is subject to question.

Observations (Graves et al. 1982) that native pecan populations exhibit a high level of scab infection, whereas native stands of other hickory species rarely display such infection, suggests that these other species possess resistance factors not prevalent in pecan. It has been our observation that, among native pecan populations of the lower Mississippi Delta region where environmental conditions are conducive to scab development, approximately 60% of the trees will exhibit noticeable scab infection. These observations seem to be borne out by published accounts of KenKnight (1968). In contrast, it was also noted that among native stands of other hickory species in the same region, infection by the scab fungus was rare. This would suggest that these other species possess resistance factors not prevalent in pecan, and that perhaps through interspecific breeding, quality resistance may be linked to desirable horticultural characteristics.

INTERSPECIFIC AND INTRASPECIFIC HYBRIDIZATION

Natural hybrids between hickory species apparently are fairly common. There have been several reports of natural hybrids from crosses between pecan and a number of other hickory species (hicans) including water, *Carya aquatica* (Michx. f.) Nutt. (Stone et al. 1965), shellbark, *C. laciniosa* (Michx.) Loud. (Rehder 1940), shagbark, *C. ovata* (Mill.) K. Koch. (Crane et al. 1937), mockernut, *C. tomentosa* Nutt (Rehder 1940), and bitternut, *C. cordiformis* (Wangh.) K. Koch. (Rehder 1940). There have been published reports of controlled crosses between pecan and other hickory species (Jaynes 1969, McDaniel 1954, McKay 1961, Thielgas et al. 1977, Windham et al. 1981), and likewise there have been verbal reports of such crosses by hobbyists and growers. However, there have been few follow-up reports concerning the results of these crosses and/or the possible use of such hicans in controlled back-crosses with pecan.

Most hickories have a somatic chromosome number of 32, but some, such as pignut, *C. glabra* (Mill.) Sweet, red, *C. ovalis* (Wangh.) Sarg., sand, *C. pallida* (Ashe) Engl. & Graebn, and mockernut are tetraploids with a chromosome number of 64 (Jaynes 1969). Natural crosses between diploids and tetraploids have been reported (Palmer 1937, Rehder 1940). Although the resulting triploids are sterile, it is theoretically possible to create fertile hybrids from such crosses by doubling the chromosome number using colchiploidy techniques, or perhaps by genetic manipulations that may someday be possible should success be achieved in somatic embryogenesis through tissue culture methods.

Current knowledge of resistance has been utilized in parental selections in an ongoing interspecific, intraspecific hybridization program on the Mississippi State University campus. Progeny of these crosses have been established in a nursery to be used for evaluation of resistance phenomena, studies relative to mode of inheritance of resistance factors, and as a possible source of parental materials for a resistance breeding program. An effort has been made to achieve as many crosses between pecan and other hickory and walnut species as possible. To date, a total of 76 interspecific and 5 intergeneric crosses have been accomplished involving 7 *Carya* spp. and 1 *Juglans* spp. In addition, 132 intraspecific crosses involving pecan cultivars of interest have been made (Graves et al. 1989). An effort is currently being made to utilize isozyme methodologies to verify parentage of crosses.

RESISTANCE FACTORS

Resistance to any pathogen is likely to be the result of multiple factors in nature. Physical and chemical deterrents to pathogen spore germination and penetration are components of a plants defense system. Wetzstein and Sparks (Wetzstein and Sparks 1983) correlated pecan leaf resistance to *C. caryigenum* and the presence of fewer glandular trichomes and a greater frequency of collapsed trichomes, in addition to abundant phenolics in the palisade parenchyma and bundle sheath cells. Glandular trichomes were apparent on both the abaxial and adaxial leaf surfaces and occasionally exhibited extruded material. Susceptible cultivars also had a greater diversity in trichome diameter than resistant cultivars. Latham and Rushing (Latham and Rushing 1988) found that among inoculated *C. caryigenum* conidia landing near trichomes, a majority (82.2%) of the conidia upon germination grew to the base of the trichomes where penetration occurred. Influence of trichomes may result in altered patterns of leaf wettability, humidity at the leaf surface, solution retention and conidia penetration (Grauke et al. 1988, Wetzstein and Sparks 1983).

Wood et al. (Wood et al. 1988) noted several phylloplane associated substances that either had an inhibitory, neutral or promotive effect on *C. caryigenum* conidial germination. They hypothesized that pecan susceptibility to scab is partially dependent upon phylloplane composition.

Work having to do with the relationship of plant constituents to scab resistance may be summarized with the following notations:

1. Certain plant constituents common to the Juglandaceae and considered of significance in disease resistance have been identified. Plant phenolic derivatives have been identified as major among these (Hedin et al. 1980, Hedin et al. 1979, Laird et al. 1990, Langhans et al. 1978).

2. Juglone, the condensed tannins, and isoquercitrin have been identified as principal phenolics of pecan and hickory, and they obviously play a role in disease resistance. Juglone, which also occurs in walnuts, has been shown to be a chemical host factor associated with resistance of pecan and other members of the Juglandaceae to scab (Borazjani et al. 1983, Borazjani et al. 1985, Graves et al. 1979, Hedin et al. 1979, Langhans et al. 1978). Juglone and hydrojuglone glucoside have also been

correlated with resistance in juvenile leaves of black walnut to anthracnose by other researchers (Cline and Neely 1984). The condensed tannins and isoquercitrin, extracted from pecan, have been shown to be highly toxic to the scab pathogen, although field correlations have not yet been completed (Laird et al. 1985, Laird et al. 1990).

3. Microspectrophotometric methods for histochemical localization and quantitation of these three principal phenolics in hickories and walnuts have been developed and are being used to ascertain occurrence within tissues and ultimately the full role of phenolics in disease resistance. The respective levels of each of these allelochemicals in combination may determine the quality of resistance (Diehl et al. 1989, Diehl et al. 1990, Graves et al. 1986).

4. Research has indicated a highly significant difference in phenolic levels between infected and noninfected tissues. The host responds to challenge by the pathogen with increased phenolic production. Thus quality resistance cannot be determined solely on the presence of preformed phenolics. Evidence indicates that the total phenolic presence is a better indicator of quality resistance than any of the principal phenolics alone (Diehl et al. 1990).

5. Progress in procedures that will combine the specificity of the antigen-antibody reaction plus a fluorescent probe to localize the phenolics *in situ* has been achieved (Diehl, unpublished). These immunofluorescent procedures together with electron microscopy methods will provide validation of the histochemical procedures. Transmission electron microscopy (TEM) procedures have been developed for localization of phenolics within cell vacuoles (Diehl et al. 1988).

6. Both TEM and scanning electron microscopy (SEM) methods have been developed, and are being utilized to follow fungal infection processes of the scab fungus in pecan which will be related to both preformed phenolic presence and host phenolic responses to the invading pathogen (Diehl et al. 1990, Diehl et al. 1988).

In summary, selection for resistance to many foliar diseases appears to be feasible. However, scab, the most serious disease, poses a more difficult problem. Considerable genotypic diversity of the scab pathogen, *C. caryigenum*, seems obvious in nature. In addition, the fungus exhibits characteristics that would permit necessary genetic recombinations that may account for the obvious adaptive capability present. Historical observations, results of selection attempts, together with the genetic diversity and adaptability of the pathogen suggest that selection of cultivars with lasting resistance to scab within the species *C. illinoensis* is subject to question. By contrast, the low level of scab incidence on other *Carya* spp. and the apparent ease by which hican hybrids can be achieved creates interesting possibilities for transferring quality resistance genes to horticulturally acceptable pecan types.

Factors associated with resistance have been identified. Three principal hickory phenolics identified have been shown to be highly toxic to the scab pathogen, and indications of a strong role in resistance have been detailed. Research has indicated that there is a host response to the pathogen by increased phenolic levels, and that total phenolic levels within challenged tissues greatly influence resistance. Histochemical procedures for quantitation of phenolic response plus enumeration of other resistance factors should permit evaluation of parental sources and subsequent breeding progenies for an intelligent resistance breeding program. The collection of interspecific crosses begun at Mississippi State University may prove a strong resource for such a program.

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DEVELOPING A WETNESS-BASED FUNGICIDE SCHEDULE FOR THE CONTROL OF PECAN SCAB, *CLADOSPORIUM CARYIGENUM* (ELL. ET LANG.) GOTTWALD AT MULTIPLE SITES USING THE REMOTE AUTOMATED INTELLIGENCE NETWORK, RAIN

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ABSTRACT

Decision rules that base spray-timing for control of pecan scab [*Cladosporium caryigenum* (Ell. et Lang.) Gottwald] on environmental conditions rather than on a calendar schedule were tested in eight pecan orchards [*Carya illinoensis* (Wang.) Koch] ranging in location from the Piedmont to the southern Coastal Plain, Georgia, USA during 1990.

Using the environmental sensors and communication capabilities of the distributed computer network RAIN, we monitored leaf wetness in each orchard. When wetness in an orchard exceeded 16 continuous hours, we notified the grower to apply Orbit (propiconazole, Ciba-Geigy) on a 5 acre experimental plot. Growers managed a check plot at each location using standard agronomic practices. Scab infection was monitored by sampling leaves weekly and counting scab lesions.

Six of the eight experimental plots had equal or better scab control with the same or fewer applications than check plots. Growers at the other two sites applied fewer sprays, but got poorer control. The grower at one of these two sites missed a recommended application. At the remaining site, scab was not controlled successfully under either the experimental or the standard management practice.

Early applications of Orbit did not seem critical for control of scab, but spray timing in early May was crucial. Despite a variety of wetness conditions across sites, scab lesions appeared about April 21 at all sites except one.

Circumstantial evidence from several sites suggests that 14 hours of continuous wetness was sufficient for scab development. Comparison of multiple sites was invaluable for testing the rule under a range of natural wetness conditions. This pilot study suggests that a general fungicide application rule can be developed for scab control based on continuous hours of leaf wetness.

INTRODUCTION

Pecan scab, *Cladosporium caryigenum* (Ell. et Lang.) Gottwald (= *Fusicladium effusum* Wint.), is the most destructive and prevalent disease of pecans [*Carya illinoensis* (Wang.) Koch] in the United States (Gottwald and Bertrand 1982, Latham 1982). Pecan scab forms 1-4 mm olive or black oval lesions on leaves, rachii, twigs, and nut shucks. Tissues are most susceptible when young and actively growing.

Severe cases of scab may cause defoliation, but the primary effects are reduction of photosynthetic capacity (Wood et al. 1984, Gottwald and Wood 1985) and development of lesions on the shells. Net photosynthesis can be reduced by as much as 42% by high disease levels (ca. 54-76%) (Gottwald and Wood 1984). Shell lesions can cause incomplete development of the nut (Nolen 1926). Late-season disease, while not significant to current season crop yield or nut quality, may affect carbohydrate reserves for the following year (Wells et al. 1976; Gottwald and Bertrand 1983, 1988).

Pecan varieties vary in susceptibility to scab (Demaree and Cole 1925). Varieties regarded as scab resistant tend to become susceptible with time (Cole 1957). Strains of the fungus have adapted to different pecan varieties and environmental conditions (Hunter et al. 1978), infecting varieties previously regarded as scab resistant (Cole 1957).

Scab Life Cycle

Fluctuations in temperature, relative humidity, and rainfall are correlated with increased severity of pecan scab (Valli 1964; Gottwald 1982; Hunter et al. 1978; Latham 1979, 1982). Scab overwinters as stromata on shucks, rachii, or stems (Latham and Garrett 1971; Latham and Hammond 1983; Littrell 1980). Spore release from stromata begins up to two weeks before first foliage, and peaks about mid-April, at bud break (Gottwald 1982; Latham and Rushing 1988). Rainfall contributes to scab infection by providing high humidity, dispersing spores by splash, and by washing protective fungicides from leaf surfaces.

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Heavy rain washes spores from foliage. Spores are dispersed locally by rain, and are carried long distances by wind. Relative humidities lower than 89% promote air-borne spread of spores (Gottwald and Bertrand 1982, Hunter et al. 1978).

Free water favors rapid spore germination, but germination can occur in the absence of free water at humidities exceeding 95% (Converse 1956). Spores are produced from 20-30°C, but 25°C is optimum (Hunter et al. 1978). Spore production decreases sharply below 15°C. At 25°C, the time required for 50% of stromata to produce spores varied from 6-24 hours.

Spores can infect foliage in 6-12 hours. Infection requires temperatures between 19-29°C. Incubation varies with temperature, humidity, variety, and virulence of the scab strain. Nolen (1926) reported 5-21 days before visible lesions appear, while Valli (1964) reported 7-10 days. The infection cycle repeats many times during the growing season, particularly during wet seasons, under irrigation, and on varieties which continually flush new growth.

Most fungicides for scab control are not effective when applied post-infection, and must be used prophylactically to prevent infection. The standard disease prevention program in Georgia calls for fungicide applications on a 14-day interval from bud break until pollination (McVay and Ellis 1979). 90% or more of the total leaf surface develops between bud break and pollination. After pollination, a 21-day calendar schedule is recommended.

As-Needed Spray Timing

Fungicide application schedules based on weather conditions rather than calendar intervals have proven successful on Potato blight with the Blitecast system in Pennsylvania (Krause et al. 1975). Growers reported rainfall, relative humidity, and temperature in their fields by telephone to a Blitecast operator, who entered this information into a computer terminal. The operator then returned the disease forecast and spray recommendation to the grower.

Three experimental pecan scab spray schedules based on analyses of weather data have proven better at reducing scab incidence than calendar-based schedules (Hunter et al. 1978, Miller et al. 1979, McVay and Gazaway 1980). Hunter et al. (1978) saved three sprays with a weather-based spray rule using 100 accumulated hours of leaf wetness as an application threshold. In a mild scab year, wetness in the experimental Schley plot required six applications of triphenyltin hydroxide (Du-Ter, Griffin Ag Products), while the calendar-based check plot received nine applications. The last three experimental applications were late season (August), and could possibly have been omitted (Gottwald and Bertrand 1988). Foliar scab control was as good, and scab on nuts was lower (0-1% vs. 22-27%), in the wetness-based experimental block as in the check.

Miller et al. (1979) tried timing applications of Du-Ter on experimental blocks of Schley and Stuart using 120 and 240 accumulated hours as thresholds. In a wet year, the calendar-based check blocks received ten sprays, the 120 hour experimental blocks required 17 sprays, and the 240 hour experimental blocks called for nine sprays. The 240 hour blocks, while using one less spray, had more scab than check blocks. The 120 hour blocks had better scab control on foliage and nuts, but required 70% more sprays than the recommended calendar-based procedure.

Miller and his co-workers (1979) wondered why Hunter et al.'s (1978) 100 hour rule required only 6 sprays at Byron, while their 120 hour rule called for application of 17 sprays. While differences in distribution and amount of rainfall explain some of this difference, Miller et al. (1979) also suspected equipment variations between the two studies. Miller et al. (1979) used a hygrothermograph to estimate hours of leaf wetness.

McVay and Gazaway (1980), in an attempt to consolidate the earlier studies and fine-tune the spray threshold, used 120 accumulated hours of leaf wetness to determine their schedule. They applied Du-Ter in two 20 acre blocks of Stuart. Both blocks received the first spray together. McVay and Gazaway (1980) used an M. DeWitt leaf-wetness indicator to indicate when the application threshold had been reached in the experimental block. A 5-day grace period was observed after each spray on the experimental block before again accumulating wetness hours.

When the experiment was stopped in mid-August, the conventional block had received nine sprays, and the experimental block had received eight applications. The five day post-spray hiatus resulted in an actual average of 149.5 accumulated hours between experimental applications. Scab control on the nuts (91% vs. 80%) and leaves (90% vs. 79%) was better in the experimental block than in the conventional treatment.

Curative Post-Infection Properties of Orbit

Latham and Hammond (1983) discovered that propiconazole (CGA-64250), a triazole-derivative fungicide, had curative properties for after-infection scab control. In the laboratory, propiconazole prevented growth of scab inoculated up to five days earlier. Six- and 8-day-old infections showed 3% and 23% survivorship relative to untreated checks. Antifungal activity persisted for 15-18 days. This propiconazole formulation is now registered (Orbit, Ciba-Geigy) for use on pecan scab. The curative post-infection effect of Orbit makes it well-suited for use with a spray timing rule, since there is time to recognize weather conditions favoring scab and apply the fungicide.

IPM Considerations for a Spray Timing Rule

The blackmargined aphid, *Monellia caryella* (Fitch); the yellow pecan aphid, *Monelliopsis pecanis* Bissell; and the black pecan aphid, *Melanocallis caryaefoliae* (Davis) are highly detrimental to pecan production (Ellis et al. 1983). A season-long standing crop of one individual of *M. pecanis* per leaf reduced in-shell nut yield from a 70-year-old Stuart orchard by 2.41 kg/tree (Wood et al. 1987). 18.13 kg/tree were lost to the same level of *M. caryella*.

The biological control of pecan aphids by beneficial fungi directly relates to the control of pecan scab. Ekbom and Pickering (1990) found that, under suitable field conditions, infections from conidia of an entomopathogenic fungus in the Neozygitaceae midway between *Neozygites* and *Thaxterosporium* can cause high mortality in fall pecan aphid populations. This Entomophthorales fungus has potential as a natural biological control agent of pecan aphids.

Unfortunately, this fungus is sensitive to triphenyltin hydroxide (TPTH) used against pecan scab. Pickering et al. (1990) found that fungal-induced mortality rates of aphids in sprayed trees were half those in unsprayed trees. The two primary pecan production problems, then, are integrated; if growers could save applications of fungicide to prevent scab, they might also increase the biological control of aphids by naturally-occurring pathogens, and reduce the need for insecticides for aphid control later in the season.

Multi-Site Experimentation and RAIN

The interpretation of previous work on scab fungicide timing has been complicated by differences in weather conditions imposed during the tests. Weather profoundly affects scab pressure and fungicide application frequency, and is clearly beyond the control of investigators.

If an experiment is performed at only one site, then only one set of weather conditions is imposed upon it. If, however, a number of sites are investigated, the array of sites can be expected to experience a natural range of variation in weather conditions. Multi-site experiments provide insights into the performance of the system under a range of natural conditions (Hargrove and Pickering 1991). This is not experimentation in the classical sense, since there may be other differences among sites besides the weather conditions. Such differences, however, also exist in a single-site experiment repeated over time.

We have established a distributed computer network of environmental monitors, the Remote Automated Intelligence Network (RAIN), for conducting multi-site research on the effects of weather on biotic interactions (Pickering et al. 1990). Each RAIN remote station, based on a Tandy Model 102 portable computer, records meteorological parameters hourly, and automatically makes a nightly telephone call to Athens to report sensor data and exchange electronic mail.

Because there is only a 24-hour lag in data reporting with RAIN, we can monitor wetness conditions at all sites from a central location. Using the electronic message capability of RAIN, we can notify a grower that the wetness threshold has been exceeded in his orchard, and that a spray should be applied.

MATERIALS AND METHODS

We used an electronic sensor to monitor leaf wetness in pecan canopies. The leaf wetness probe (LWET, Electronically Monitored Ecosystems, Berkeley, CA) detects a film of moisture across a series of gold contact fingers separated by gaps of different widths. Mounted horizontally among the pecan leaves, the leaf wetness sensor functions like an artificial leaf. The sensor returns values between 0 and 31; however, we considered any reading higher than 0 to be sufficiently wet for scab development.

Selection of a Spray Rule

Earlier rules for fungicide spray timing were based simply on accumulating hours of wetness, and did not consider whether wet periods were continuous or interspersed with periods of dryness. We suspected that the critical factor was whether the longest continuous period of wetness was enough to allow sporulation, dispersion, and infection to start a new scab cycle. Dry periods experienced during scab development might arrest spore production or germination and prevent spread.

We formulated an application rule based on longest continuous periods of leaf wetness. Although spore production has been shown to vary with temperature, relative humidity, and rainfall (Demaree 1924; Gottwald 1982; Gottwald and Bertrand 1982; Latham 1972, 1982; Pady et al. 1969), we assume that sufficient inoculum is always present for scab infection to occur under favorable conditions.

If we completely prevented scab during the test, we would learn little about the lower limit for a scab spray rule. Similarly, if all sites developed scab, we would learn little. Gottwald (1985) reported that the greatest number of scab lesions resulted after 36 continuous hours of leaf wetness, with a sharp increase in the number of lesions occurring from 8-12 continuous hours. Gottwald's (1985) figures probably represent minimum times necessary for development under constant laboratory conditions. Because we hoped to allow intermediate scab infestations at different sites to evaluate our threshold, we chose a rather liberal 16-hour application rule.

Experimental Design

During the 1990 season, growers representing eight orchards ranging in location from the Piedmont in the north to the southern Coastal Plain, Georgia, USA, agreed to collaborate with us to test the 16-hour scab spray rule. All sites had RAIN stations in each orchard that were equipped with two temperature probes, two leaf wetness probes, and an automatic 0.01 inch tipping bucket rain gauge. Varieties were controlled within sites, but varied among sites (Table 1).

Each grower established approximately five acres as an experimental area, and agreed to apply Orbit 3.6 EC (4 oz./acre) sprays within 72 hours of receiving notification from us via RAIN. Accumulation of wetness hours resumed ten days after each Orbit application. As many sprays were applied as required under the 16-hour rule.

Nearby check areas of approximately five acres of the same variety were to be managed by each grower in the usual way. Fungicides other than Orbit could be applied to the check areas. The experiment began when growers applied the first spray to their check areas, and ended at pollination.

Included in continuous wetness periods were hours during which the RAIN station recorded readings of 1 or higher from either wetness sensor or the rain gauge. Wet periods separated by short dry periods (zero readings) of up to two hours were considered continuously wet, but such dry hours were not counted when summing accumulated continuous hours of wetness.

Data Collection

Weekly, from two weeks post-budbreak until June, the growers randomly collected five compound leaves from each of ten trees in each of their two plots and mailed them to our laboratory. Since each new lesion represents a separate infection event, scab transmission is reflected by the number, rather than area, of lesions. Visible scab lesions were counted on all leaves. The same person scored check and experimental leaves to reduce interobserver bias. Growers counted aphids per leaf in both treatments while collecting leaves for quantification of scab damage.

RESULTS AND DISCUSSION

Six of the eight experimental plots had equal or better scab control with the same or fewer applications than check plots. Growers at the other two sites applied fewer sprays, but got poorer control. The grower at one of these two sites missed a recommended application. At the remaining site, scab was not controlled successfully under either the experimental or the standard management practice.

No site applied more sprays to the Experiment than the check (Table 2). Check plots and experimental plots received an average of 3.5 and 2.5 applications, respectively.

Growers at WTY and WBP, contrary to instructions, used other fungicides in addition to Orbit in experimental plots. WPB used triphenyltin hydroxide (TPTH) (Super-Tin, or Du-Ter), and WTY used N-dodecylguanidine acetate (dodine, Cyprex) as well. Neither Dodine nor TPTH provide the curative post-infection effect of Orbit. The 3-day curative capacity and the 10 day residual effect of Orbit were integral to the spray rule.

Nevertheless, fewer spray applications of all types were made on the experimental plots at these sites than on the check plots.

Growers at WIB, WMP, WPB, and WTY, worried about being unable to complete an application due to inclement weather, applied sprays only on every other tree row (Table 2). Remaining rows would be sprayed a few days later. If spraying was interrupted by rain, wind, or equipment breakdown, more of the orchard had at least received one-half coverage. Without this cultural practice, if the application was not completed, part of the orchard would have total coverage, but part would remain unprotected. Half-sprays were applied to the experimental plot at WIB, but applications were made conventionally on experimental plots at all other sites.

Scab infection, wetness, and actual fungicide applications in each orchard are shown for the eight sites in Figures 1 and 2. Vertical bars represent the maximum number of continuous hours of leaf wetness in the orchard each day. Fungicides should have been applied to experimental plots whenever vertical bars exceeded the horizontal line at 16 continuous hours. The orchard was then considered protected for a period of ten days. If the 16-hour spray threshold was exceeded before midnight, hours beyond 16 were included in the bar for the following day. All axes in both Figures are scaled identically for comparison.

Scab infection curves were generally parallel in the check and experimental plots, indicating that both plots responded to the same factors. Despite a variety of wetness conditions across sites, scab lesions appeared about April 21 at all sites except WRC. Scab appeared at WRC a little earlier (April 15), despite its northernmost location and the dry conditions at WRC before this time.

There was wide variance in grower interpretation and adherence to the standard scab control recommendations advocated by Cooperative Extension. Most growers did not apply sprays on the check plots strictly by a 14-day calendar interval as recommended, but tried to take into account relative wetness in the orchard. Obviously, growers already feel that an as-needed application schedule has potential.

Generally, the spray-timing rule was more successful and/or conservative than conventional management. Intermediate conditions of scab were created, and a range of scab control was achieved experiment-wide. Experiment and check plots were compared statistically by date within sites using two-sample t-tests. Statistical comparisons across sites are not necessary or possible (Hargrove and Pickering 1991).

WTY Experiment plot achieved better scab control with fewer applications than its check. WFR Experiment plot attained better scab control with an equal number of applications as its check. WJM and WIB Experiment plots had equal scab control with fewer applications than their checks. WPF and WRC Experiment plots obtained equal control with equal applications compared to their checks. WMP and WPB Experiment plots, however, produced poorer scab control with fewer applications than their checks.

WRC, one of the wettest sites, had little problem with scab despite early appearance of lesions (Figure 1). Inoculum may not have been pervasive at this northern site, or spores may have been washed from foliage by the wet conditions. The check and Experiment application schedules differed only in the timing of the last spray. The 16-hour rule at WRC required the application of sprays on the experimental plot every 14 days, the same schedule that would result from the current calendar-based recommendation. This grower used wetness considerations from his RAIN station to temper the management of his check plot. Thus, the check and Experiment designations could well be reversed at this site!

WFR missed a recommended application on the Experiment plot on 4/20 (Figure 1). Scab lesion development between 5/3 and 5/10 probably would have been prevented by this missed application. The grower at WFR made the 5/13 application on the Experiment plot on time. Residual effects of the first applications on Experiment and check plots had disappeared by this time. Plot differences in scab infestation at WFR, then, were probably due to the 4-day difference in applying these second sprays, indicating the importance and potential for spray timing. Significant differences were achieved by 5/10 ($\alpha \leq 0.0032$), and remained so for the duration of the study.

Half-sprays on check and experimental plots at WIB were timed identically until early May (Figure 1). Because the duration of an effective residual half-applications of Orbit is unknown, correlation of early scab development with particular periods of wetness is difficult. The second Experiment spray was applied two days after the second check spray. Scab lesion counts diverge after this application, although not significantly ($\alpha \leq 0.224$ and 0.258 for 5/15 and 5/25, respectively).

WJM was one of the driest sites (Figure 1). The second spray was applied to the Experiment by mistake; the orchard had experienced only 14 continuous hours of wetness. Had this application not been made, we could have seen whether the 14 continuous hours of wetness on 5/5 or the 13 hours on 5/9 were sufficient for scab development. Scab counts from the experimental plot were significantly lower than check plot counts for the last two leaf samples ($\alpha \leq 0.025$ and 0.008, respectively).

The 2nd applications on both the Experiment and check plots were well-timed at WPF (Figure 2). The 10-13 continuous hours of wetness between 4/20 and 5/1 produced little scab development between the first and second leaf samples. The 15 hours of wetness on 5/18, however, may have been responsible for the increase in scab on the final set of leaf samples, suggesting a slightly lower threshold for scab infection. Differences in the timing of the first scab applications on Experiment and check (and the tardiness of the first experimental application) at WPF made little difference in scab control despite relatively wet periods between 4/20 and 5/1. Scab lesion counts at the end of the experiment were not significantly different ($\alpha \leq 0.681$).

WPB failed to apply any fungicides on the experimental plot during May (Figure 2). This grower clearly missed a spray application after a period of extreme wetness on 5/8 and 5/10 (21 and 29 hours, respectively). Scab lesion trajectories diverge seven to nine days later at next leaf sample (5/17), giving an estimate of scab incubation time. By this time, any effects of the 4/3 experimental spray were gone. Sub-threshold wetness (15 hours) on 5/2 may have been responsible for scab infection seen in leaf samples from 5/9; this would also have been an incubation time of 7 days. Only two sprays were applied to the experimental plot; one early and one late. Not surprisingly, then, the experimental plot exhibited textbook exponential scab growth.

Scab was controlled in the conventional plot at WPB with 11 spray passes comprising six applications of four types of fungicides: TPTH, dodine, Orbit, and Topsin-M (Figure 2, Table 2). Scab increased in the check plot despite heavy use of half-sprays of Orbit until switching to other fungicide compounds on 5/14.

WMP showed good timing of spray applications according to the 16-hour rule, yet scab grew out of control (Figure 2). Scab infestation in the check plot also escaped control at this site, but the outbreak was significantly less severe than in the experimental plot ($\alpha \leq 0.005$ by 5/03). Applications on the check included half-sprays of TPTH, Orbit, and ultimately Topsin-M. Increases in scab on 5/17 may correlate with the 26-hour continuous period of wetness on 5/9, further indication of a seven to eight day incubation period for scab in the field. Scab control was inadequate in the experimental plot with three applications of Orbit according to the 16-hour rule.

The grower at WTY, fearing resistance to Orbit, switched to two other fungicides for the 3rd and 4th experimental plot applications (Figure 2). Significant flattening and divergence of the scab curves on 5/15 and 5/23 following the 2nd application of Orbit ($\alpha \leq 0.002$ and 0.040, respectively), however, suggests that scab at WTY remained somewhat sensitive to Orbit. This 2nd Orbit application probably accounted for the differences observed for the remainder of the experiment. Scab development before the 5/9 application likely resulted from the below-threshold 13- or 14-hour continuous wetness around 4/23. Nevertheless, WTY experimental plot showed significantly better scab control with the 16-hour rule while saving a spray application ($\alpha \leq 0.022$ by 6/05).

Scab infestation in check plots at WPB not controllable by heavy half-sprays of Orbit was brought under control using non-Orbit fungicides, and scab increased dramatically in WMP Experiment and check plots despite apparently well-timed Orbit applications. Half-sprays may be ineffective. The cultural practice of applying half-sprays may speed development of resistance, since it results in twice as much exposure of scab to less-than-lethal doses. Benlate resistance in certain scab strains is well-known (Ellis et al. 1983).

Aphid Densities

For all six sites where aphid density data are available, aphid densities in experimental plots were equal to or lower than aphid densities in check plots (Figures 3 and 4). Aphid densities were comparable in experimental and check plots at WIB and WPB, but densities were lower in experimental plots at WFR, WPF, WMP, and WTY. Whether these decreased aphid densities were due to mortality from the beneficial Entomophthora fungus is not known, since only density and not fungal incidence was measured.

CONCLUSIONS

This pilot study suggests that it will be possible to develop an effective and conservative fungicide application rule for scab control based on leaf wetness. A general rule will likely not, however, be robust enough to be applied without a modicum of understanding. Considerations of varietal susceptibility, scab pressure, and integrated management concerns will be necessary when timing fungicide applications. Growers already make such considerations in interpreting the existing recommendations.

Comparison of multiple sites was invaluable for testing the rule under a range of natural wetness conditions. Considering only WRC, we might conclude that spray timing is unimportant, and scab is not a problem. Given only WMP, we would conclude that scab cannot be controlled by as-needed sprays, and increase calendar application frequency. Results from all sites, however, make it clear that as-needed spray timing can be successful.

Different degrees of grower compliance with the 16-hour rule added to the mix of conditions. The robustness of the multi-site technique was strengthened by these additional intermediate conditions, whereas a single site experiment might have been ruined. A useful spray-timing rule must work not only under the tightly controlled conditions of an Agricultural Experiment Station field test, but as implemented by growers under actual production conditions.

Circumstantial evidence from WPF and WTY suggest that more than 13 continuous hours of wetness are required for scab development in the field. Likewise, instances at WPF and WPB suggest that 15 continuous hours may be sufficient for development of scab. Fourteen hours may be more appropriate for a timing rule. Lowering the threshold to 14 continuous hours will increase application frequency slightly, but may improve control. Correlations of scab infection with obvious periods of wetness at WPB and WMP suggest seven to nine days as an upper limit on the incubation period for scab under field conditions.

Contrary to conventional wisdom, early applications did not seem critical for control of scab. The timing of sprays in the first half of May was much more crucial. If it is possible to delay the first application of fungicide in the spring, the beneficial Entomophthorales fungus may be able to sporulate and infect first-generation aphids, where it may be better able to resist the debilitating effects of scab control fungicides. Fungal diseases like *Glomerella* and *Phanopsis* may, however, become more of a problem under reduced or delayed fungicide schedules (C. Reilly, pers. comm).

All growers involved have indicated willingness to participate again, and we anticipate involvement by more growers at additional sites. Next season, we will increase the frequency and regularity of scab monitoring and aphid counts. A larger data set will allow modeling scab epidemiology goodness-of-fit with wetness conditions.

Contrary to current scab control recommendations, growers waited until after wet periods to apply initial sprays to check plots. This put the experimental plots in jeopardy initially, since they were not sprayed until the accumulation of 16 hours of additional wetness. We will ask growers to apply the first spray to both plots initially, then apply experimental sprays as determined by wetness.

The 16-hour rule of continuous leaf wetness generally proved more effective than calendar sprays in reducing the number of spray applications for the growers and the amount of chemicals released into the environment. Moving from calendar-based spray applications while saving money and the environment will require more sophistication and knowledge. By automating with electronic technology, we hope to increase the acceptance of low-spray solutions.

ACKNOWLEDGEMENTS

This multi-site experiment could not have been done without the cooperation of these growers: R. Cooper, J. Inman, J. and F. Marbury, B. Reese, and F. Wetherbee. P. Kirby and M. Kiser counted scab lesions. M. Camann, J. Chamberlin, R. Maxwell, C. Reilly, and J. Wenzel gave internal reviews. F. Hendrix and D. Sparks provided valuable support and advice. Department of Entomology, UGA, subsidized purchase of a needed vehicle. T. All printed graphs and slides. Work supported in part by Hatch projects H899 and H623 to J.P.

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Table 1. Pecan varieties and type of irrigation at eight sites in south Georgia used in the multi-site development of a fungicide application rule for control of pecan scab. Varieties were the same in check and experimental plots. Sites listed in order of decreasing scab susceptibility.

Site	Variety	Irrigation	County
WMP	Cheyenne	Sprinkler	Calhoun
WTY	Cheyenne	Drip	Dougherty
WIB	Cheyenne	Drip	Wilcox
WPB	Wichita	Sprinkler	Sumter
WPF	Schley	Sprinkler	Dougherty
WJM	Schley	none	Lee
WFR	Stuart	Sprinkler	Mitchell
WRC	Stuart	Drip	Upson

Table 2. Summary of types of fungicides and number of applications at eight sites during the test of a 16-hour continuous wetness fungicide application rule for control of pecan scab. "E" and "C" symbols designate fungicides applied to experimental and check areas, respectively. Half-sprays indicate that the sprayer was taken down alternate tree rows.

		Fungicide				
Site	Plot	Orbit	TPTH	Cyprex	Topsin-M	Total
WMP	C	1.5	1.5		1	4C
	E	3				3E
WTY	C	2	2		1	5C
	E	2	1		1	4E
WIB	C	3				3C
	E	2				2E
WPB	C	3	1.5	1	0.5	6C
	E	1	1			2E
WPF	C	2				2C
	E	2				2E
WJM	C	1	2			3C
	E	2				2E
WRC	C	3				3C
	E	3				3E
WFR	C	2				2C
	E	2				2E

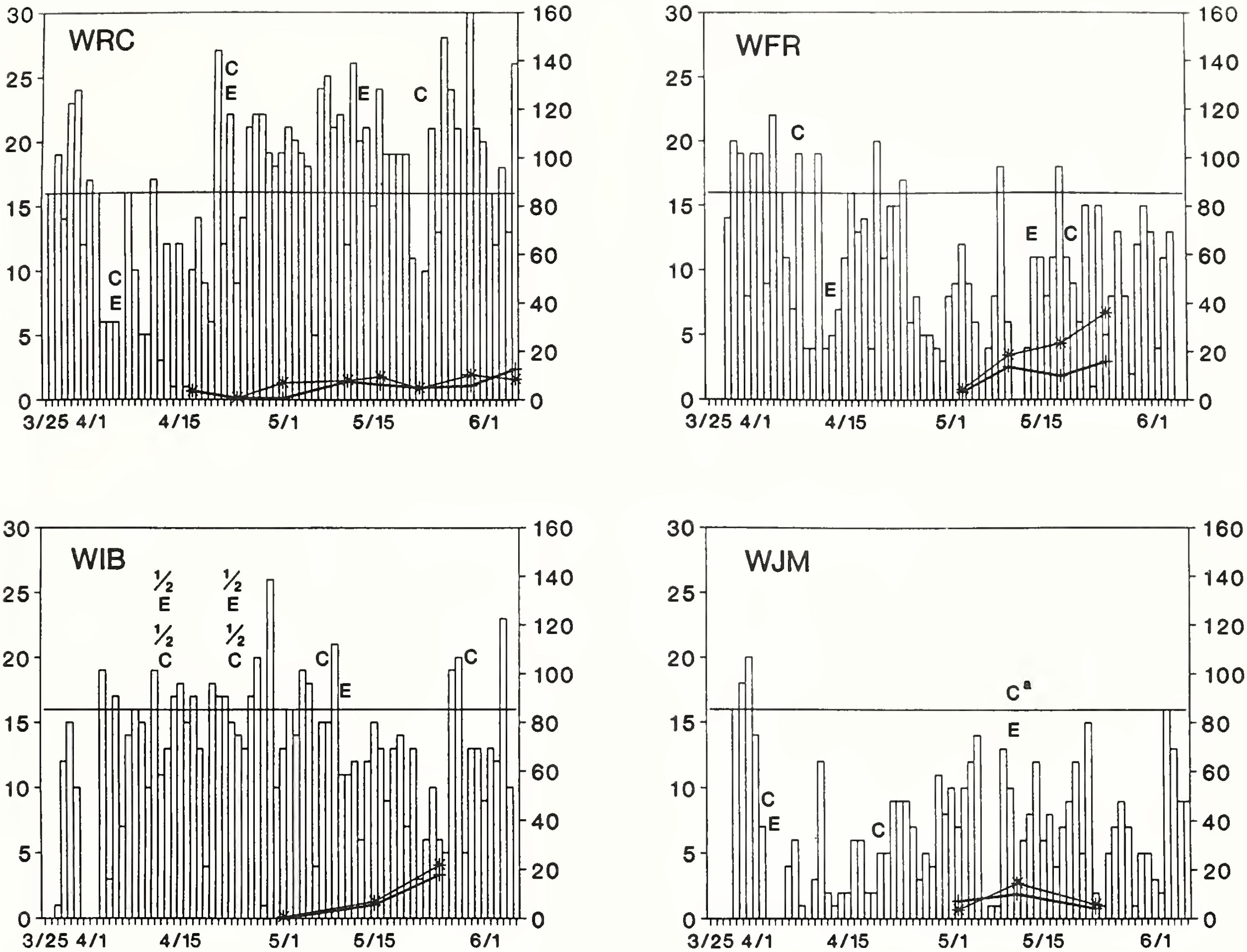

Figure 1. Relationship between leaf wetness and incidence of pecan scab, *Cladosporium caryigenum* (Ell. et Lang.) Gottwald, and response to fungicide applications timed according to a 16-hour rule at WRC, WFR, WIB, and WJM. Vertical bars represent the maximum number of continuous hours of leaf wetness in the orchard each day. Fungicides were to be applied whenever vertical bars exceeded the horizontal line at 16 continuous hours. If spray threshold was exceeded before midnight, hours beyond 16 were scored for the following day. Dark line with plus symbols is mean scab in the experimental plot, which was to be sprayed according to the 16-hour rule. Light line with star symbols is mean scab in the check plot, which was managed by the growers in the usual way. "E" and "C" symbols designate dates when fungicides were applied to experimental and check areas, respectively. "1/2" preceding the spray symbol indicates that the sprayer was taken down alternate tree rows. Superscript "a" indicates application of triphenyltin hydroxide (Super-Tin or Du-Ter, Griffin Ag Products). All other applications are propiconazole (Orbit, Ciba-Geigy).

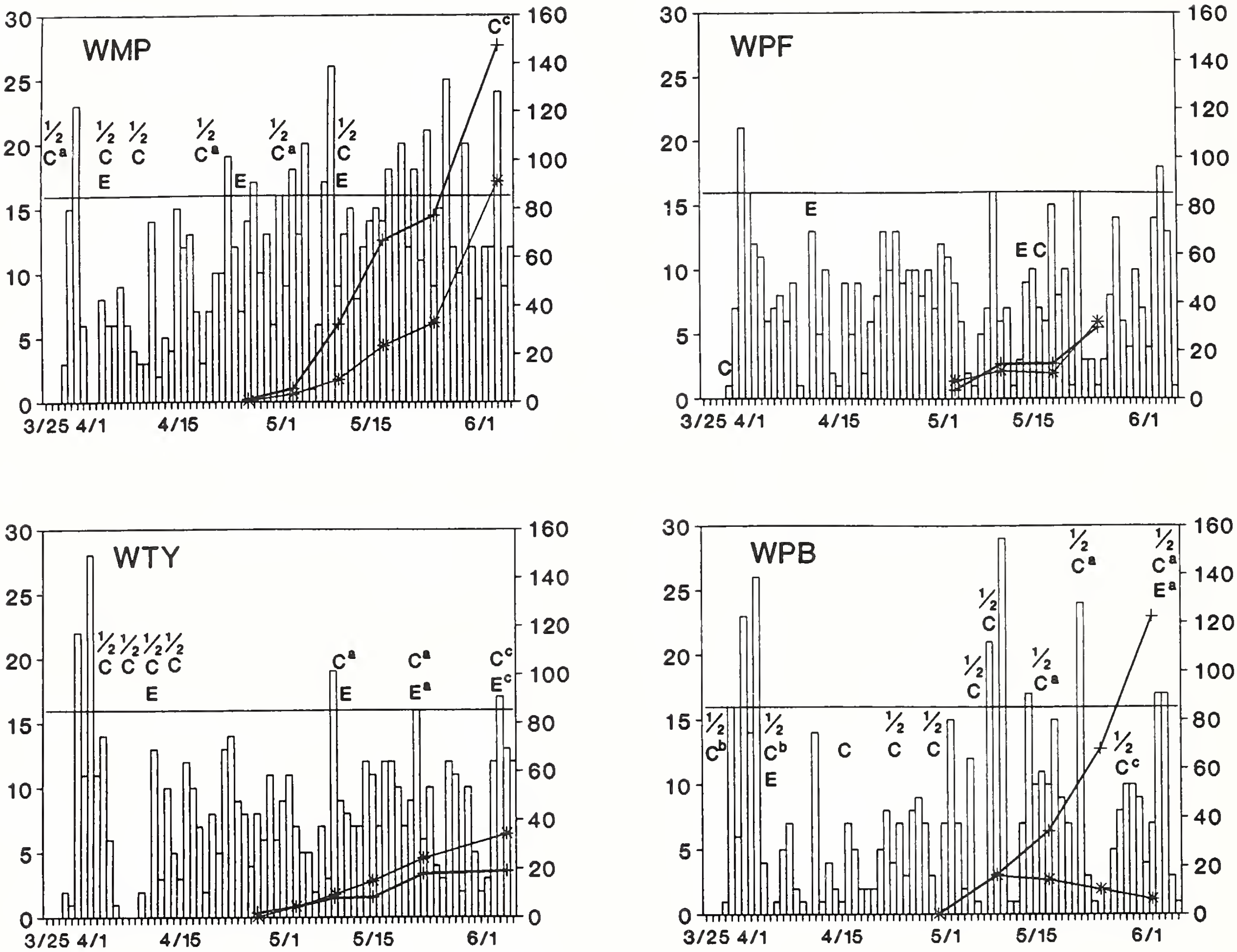

Figure 2. Relationship between leaf wetness and incidence of pecan scab, *Cladosporium caryigenum* (Ell. et Lang.) Gottwald, and response to fungicide applications timed according to a 16-hour rule at WMP, WPF, WTY, and WPB. Vertical bars represent the maximum number of continuous hours of leaf wetness in the orchard each day. Fungicides were to be applied whenever vertical bars exceeded the horizontal line at 16 continuous hours. If spray threshold was exceeded before midnight, hours beyond 16 were scored for the following day. Dark line with plus symbols is mean scab in the experimental plot, which was to be sprayed according to the 16-hour rule. Light line with star symbols is mean scab in the check plot, which was managed by the growers in the usual way. "E" and "C" symbols designate dates when fungicides were applied to experimental and check areas, respectively. "1/2" preceding the spray symbol indicates that the sprayer was taken down alternate tree rows. Superscript "a" indicates application of triphenyltin hydroxide (Super-Tin or Du-Ter, Griffin Ag Products). Superscript "b" indicates application of dodine (Cyprex, American Cyanamid). Superscript "c" indicates application of thiophanate (Topsin-M, Pennwalt). All other applications are propiconazole (Orbit, Ciba-Geigy).

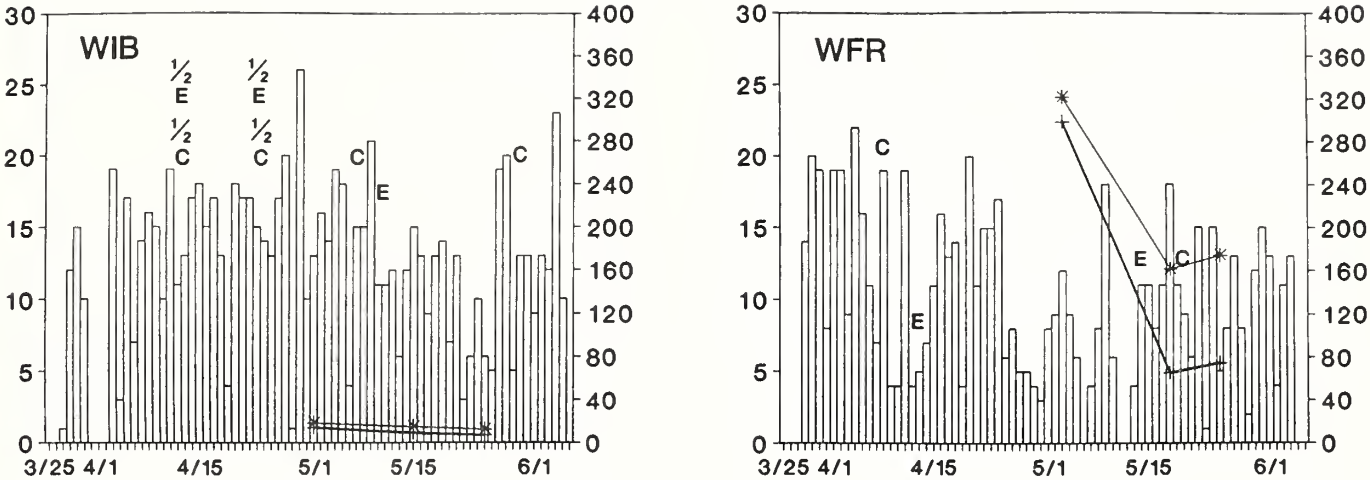

Figure 3. Aphid density per 50 compound leaves at WFR and WIB. Vertical bars represent the maximum number of continuous hours of leaf wetness in the orchard each day, as in previous figures. Dark line with plus symbols is aphid density in the experimental plot. Light line with star symbols is aphid density in the check plot. "E" and "C" symbols designate dates when fungicides were applied to experimental and check areas, respectively. "1/2" preceding the spray symbol indicates that the sprayer was taken down alternate tree rows. All applications are propiconazole (Orbit, Ciba-Geigy).

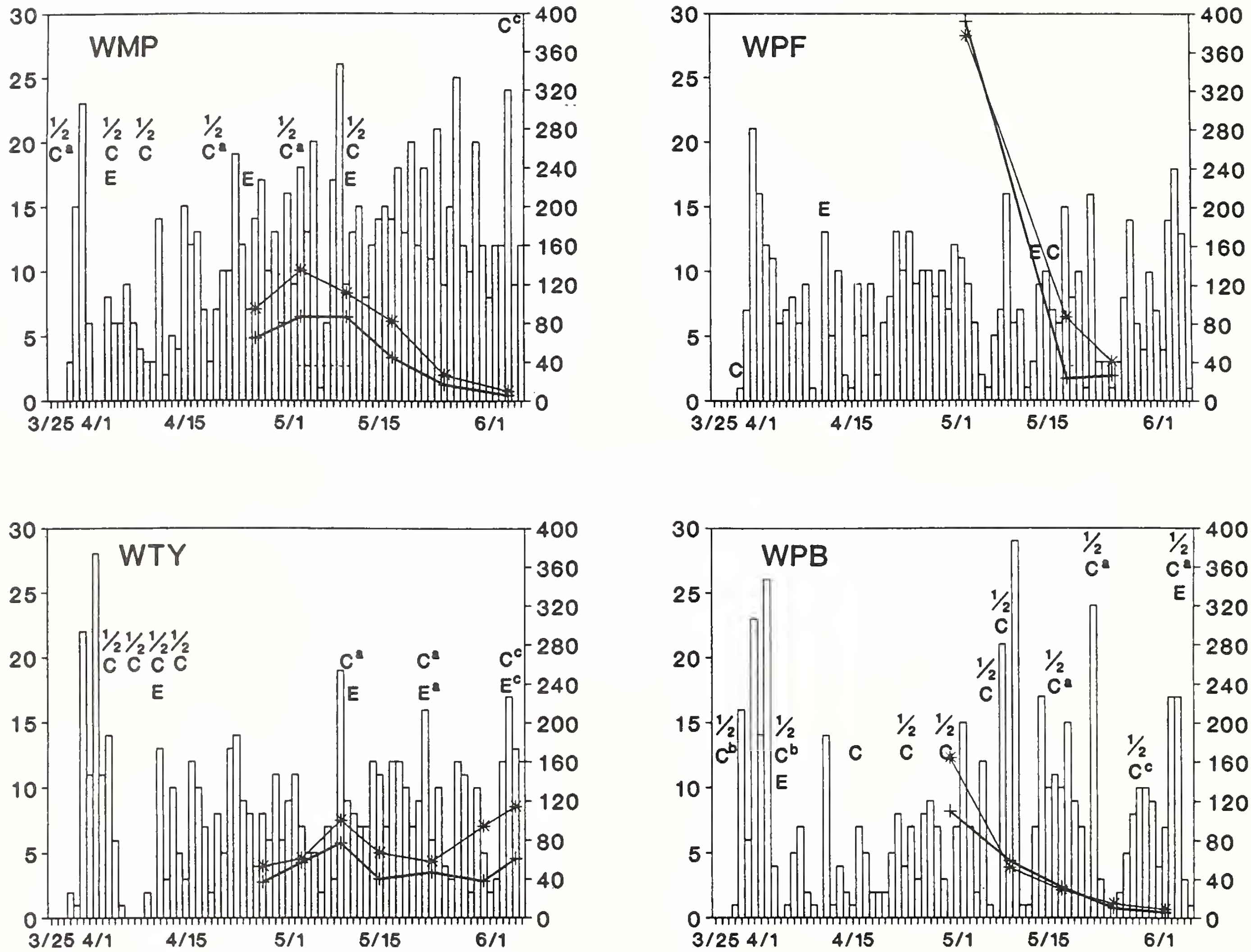

Figure 4. Aphid density per 50 compound leaves at WMP, WPF, WTY, and WPB. Vertical bars represent the maximum number of continuous hours of leaf wetness in the orchard each day, as in previous figures. Dark line with plus symbols is aphid density in the experimental plot. Light line with star symbols is aphid density in the check plot. "E" and "C" symbols designate dates when fungicides were applied to experimental and check areas, respectively. "1/2" preceding the spray symbol indicates that the sprayer was taken down alternate tree rows. Superscript "a" indicates application of triphenyltin hydroxide (Super-Tin or Du-Ter, Griffin Ag Products). Superscript "b" indicates application of dodine (Cyprex, American Cyanamid). Superscript "c" indicates application of thiophanate (Topsin-M, Pennwalt). All other applications are propiconazole (Orbit, Ciba-Geigy).

PROTECTION RAPPORTEURS

George H. Hedger[1] and Raymond D. Eikenbary[2]

INTRODUCTION

We would like to say at the outset that we had an excellent meeting location with good facilities and a stimulating atmosphere here at Unicoi State Park, Helen, GA., July 23-25, 1990. The site committee is to be commended for choosing this excellent meeting place.

We believe that the objectives and theme of the workshop "Pecan Husbandry: Challenges and Opportunities" were only partially achieved. For example, most speakers were mainly concerned with their research and/or extension activities and failed to examine short- and long-term challenges and opportunities associated with the cultivation, production and marketing of pecans. There were some indications that the speakers were aware of the need to achieve stable production with the greatest quantity and highest quality at the lowest cost per unit, this being consistent with the preservation of the environment and at the same time providing an extremely high quality food. However, in a more complimentary mode, we realize that the workshop provided a good environment from which information could be conveyed to pecan workers. The need for research and the integration of knowledge from the total spectrum of pecan-related sciences and experiences was also of great benefit. Some of the reasons that may have prevented the first pecan workshop from focusing on and accomplishing more of the objectives of the meeting are alluded to below.

Pecan management, culture, yield and pest protection are different in the southeast (AL, FL, GA, etc.) versus the midwest (KS, OK and TX), resulting in different problems and different solutions. For example, improved cultivars which are accompanied by higher fruit (nut) prices and higher yields, predominate in the southeast. Conversely, native cultivars with lower nut prices and lower yields per hectare predominate in the midwest. Therefore, the higher value of pecan in the southeast allows more intensive pest protection to be practiced than can be practiced in the midwest. Better pest protection (generally thought of as increased numbers of pesticide applications) produces a greater pesticide load which has created foliage pest problems in the southeast (aphids, mites and leafminers) while in the midwest less intensive pest management and reduced numbers of pesticide applications has resulted in concern being focused predominantly on nut pests. These include: pecan weevil, *Curculio caryae* (Horn); hickory shuckworm, *Cydia caryana* (Fitch); and pecan nut casebearer, *Acrobasis nuxvorella* Neunzig. Also, pecan diseases are of greater concern and importance in the southeast because of the higher humidity and the increased susceptibility of improved cultivars compared with the midwest.

Summary of Meeting

Our "Think Tank" entomologist, Dr. M.K. Harris (1991), envisaged future research needs by cautioning scientists about using limited genotypes in the pecan belt and having a uniform gene pool. Also, this scientist predicted the demise of chemical agriculture because of the 500+ species of insects that have been reported resistant to insecticides and the public concern for pollution of the environment and food. Harris' concern with the dependence on agricultural chemicals was addressed by many scientists. Dutcher (1991) pointed out the long range consequences if aphids were not controlled for several years and the difficulty of bringing these trees back into production.

Mizell (1991) pointed out the paucity of published articles or information concerning the effect of insecticides on various stages of beneficial insects. However, this scientist suggested using the known selective pesticides that conserved beneficials. Mizell (1991) and Dutcher (1991) pointed out that nut and foliage feeding pests must be controlled but we should concentrate on using effective insecticides that are less

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detrimental to the beneficial insects in the orchard. The planting of proper legumes to enhance and conserve beneficials for insect control was proposed by Tedders (1991), Mizell (1991), Ree (1991) and Dutcher (1991). These cover crops provide pollen, nectar, extrafloral nectaries and prey for the beneficials.

Too frequently, pesticides are hastily recommended without proper thought or consideration of other control tactics or of long range consequences. This was addressed by Tedders (1991). His excellent overview consisted of investigations using one or more multi-tactic control methods such as cultural, biological, physical and/or selective insecticides. Tedders (1991) stressed the need for sex pheromones for each of the Lepidopterous pests of pecans and stated that we lacked good information on action thresholds for these pests. More effective control of the hickory shuckworm should be obtained after McVay et al. (1991) and Reid and Eikenbary (1991) complete their independent research on proper pheromone trap placement in the tree and action threshold studies.

It was refreshing to hear Dutcher (1991) mention the problems in research and the difficulty of correlating the number of pecan weevils with the percent nut infestation because of the high variation of nuts on a tree, damage and number of weevils. This same type of variation can be expected with McVay et al. (1991) and Reid and Eikenbary's (1991) studies to correlate number of male moths caught in traps baited with the hickory shuckworm sex pheromone with infestation and yield.

Reid and Eikenbary (1991) evaluated low-input management strategies and low prices for native pecan orchards and stated that only one pesticide application could be justified economically and this should be for the pecan weevil. This definitely would reduce the pesticide load in a pecan orchard. Also, Reid and Eikenbary (1991) recommended that for low input agriculture: (1) Pest sampling methods and action thresholds should be developed based upon nut load on the trees; (2) pest monitoring methods should be fine tuned; (3) biological control of pests should be pursued; and (4) alternative sources of nitrogen should be sought.

Smith (1991), with his insect—plant interaction presentation, has pointed out the importance of chemical ecology and the broadness of our pest problems. This includes the multitrophic level relationships (plants, herbivores and entomophagous species) within the food web and how they interact. This presentation posed questions and future research challenges for many scientists in the years ahead.

Sparks (1991) suggested using temperature heat models for pecan casebearer, pheromone traps for the shuckworm, and scab control being based on growth stages and leaf wetness. Also, Sparks reported that damage by aphids was influenced by moisture stress and suggested the need for additional research in this area.

The most needed and innovative area of research that has the greatest potential for stimulating increased consumption of pecans was proposed by Sparks (1991). Sparks suggested that research is needed to determine the medicinal claims that pecans prevent prostrate problems in men, prevent certain types of arthritis and that some Mexican colleagues believe pecans are an aphrodisiac. Also, consumption of pecans by humans has been reported to lower blood cholesterol (Grundy 1986, Mattson and Grundy 1985 and J.B. Storey, Department of Horticulture, Texas A&M University, personal communication). While there is great difficulty (state and federal regulations) in using human subjects as experimental animals, there probably would be little or no trouble in obtaining volunteers for the home experimentation studies required to evaluate the aphrodisiac properties of pecans. Additionally, if the medicinal qualities of pecans prove successful, this would create a worldwide market for pecans.

Reilly (1991) suggested that in addition to scab, *Cladosporium caryigenum* (Elliot Lang), that Phytophthora, *Phytophthora cactorum* (Lebert & Cohn), and anthracnose, *Glomerella cingulata* (Ston.) Spauld and Schrenk, caused pecan fruit losses. Additionally, he suggested that a major research thrust should be directed to developing: (1) Predictive systems for disease control in contrast to calendar spraying, (2) new fungicide application technology, and (3) more emphasis on breeding resistance to diseases. Also, Latham and Goff (1991), Thompson (1991) and Graves and Diehl (1991) reported that scab may be the limiting factor in pecan production and that disease resistance is attainable. Hotchkiss (1991) suggested that stinkbugs and pecan weevil may bring phytophthora pathogens (shuck and kernel rot) from the soil into the tree. Brenneman (1991) suggested that anthracnose may cause nuts to drop and recommended the need for basic research.

Graves and Diehl (1991) pointed out the need for regional cooperation of plant breeding for scab resistance. There appeared to be a general consensus among entomologists, plant pathologists and horticulturists that more research in the area of pest density levels and corresponding damage under different conditions were needed. Hargrove et al. (1991) agreed with this view and illustrated how single site research plots are too limited in scope and this restricted data base may not provide the best information. Therefore, Hargrove et al. (1991) proposed a solution by recommending that multi-research sites (intra- and interstate) were appropriate and that a range of environmental conditions and a standard research procedure would provide a more logical and holistic picture of the research. However, multiple authored proposals and manuscripts by different agencies, states, and disciplines may be a problem for administrators in giving appropriate credit to the many contributing scientists.

Suggestions for the meeting

1. There may be a need for a pre- and post-social for meeting new scientists, renewing friendships, exchanging information, building harmonious relations and mending hurt feelings. The post-social may be needed if different and caustic views are expressed openly and frankly during the meeting.

2. There may have been a need for small group discussions, which would interact and coalesce into larger group discussions on controversial or challenging topics.

3. It may be desirable to have a central theme on controversial topics with speakers and then discussion.

4. Possibly entomologists, plant pathologists, horticulturists, etc. need to meet separately for one day then converge into a joint meeting.

5. Possibly there should be a discussion on research needs to see if research should be reoriented or a new direction should be taken by plant pathologists, horticulturists and entomologists with more interdisciplinary research.

6. Some speakers were more inclined to present only their research or extension activity and failed to state problems, needs and challenges of their work.

7. Possibly we should invite interested scientists from other countries for the next meeting and this be reflected in the title - International Meeting . . . .

8. We may want to get speakers that are high-tech scientists but are not working as pecan scientists.

9. An area of research that possibly needs discussing and investigating is having economists look at the economics of standard control methods with higher anticipated yields versus the use of low input limited pesticide and its lower expected yields.

10. Several of the participants this year suggested that the site selection committee should consider Colorado or northern New Mexico for the next meeting.

What We Have Accomplished

We brought together multiple agencies, multiple states, multiple disciplines and scientists and others to exchange information, discuss problems with some difference of opinion evolving, which was good.

The true test or evaluation of this meeting will be determined by the participants based upon contacts made, ideas gained and incorporated into their research, extension activity or job, thus making it better. The biggest challenge will be for the Planning Committee of the Second National Pecan Workshop to provide a better program than the First National Pecan Workshop. It is the belief of the authors of this manuscript that this First National Pecan Workshop will be remembered as the pinnacle for future meetings to challenge.

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THE DEVELOPMENT OF SELECTION CRITERIA FOR PECAN SEEDSTOCKS

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INTRODUCTION

At best, a review evaluates the past from the perspective of the present in hopes of anticipating the challenges of the future. For pecan rootstock development, this process is complicated by the necessity to integrate biological and economic realities, even as both undergo unforeseeable changes. A full appreciation of the subject requires 1) an appreciation for the genetic base of the species; 2) an understanding of the historic interactions between that base and a developing technology (which is driven by economics); and 3) a critical assessment of the current status of the industry, both in terms of practices and problems. With the above as a foundation, it should be possible to develop productive long-term strategies for rootstock development while anticipating, and hopefully avoiding, potential problems.

In order to discuss the history, current status, and potential of rootstock development in pecan, several terms must be defined. In the process of definition, concepts may be delineated which are crucial to resolution of both the problems and the potential solutions. A "rootstock" is the root upon which a "scion" or cultivar is grafted, or more simply, the root used as a stock. The compound genetic system of scion and stock is a "stion". The composition of stions is given in this paper as 'scion'/seedstock, where the is represented by the cultivar name, followed by "sd" (eg. 'Schley'/'Moore' sd refers to 'Schley' scions vegetatively propagated onto 'Moore' seedling rootstocks). A "seedstock" is the source of seed planted to produce seedling rootstocks. Seedlings arising from the same seedstock are considered a "family". Seedlings of a family may be full siblings (having the same pollen and pistillate parent) or half siblings (having different pollen parents). Full sib seedlings may be the result of either cross- or self-pollination. Seed produced without the intervention of man is termed "open-pollinated" seed, the parentage of which will depend on the composition, spacing and dichogamy of associated trees. A "population" is a loosely defined spatially associated assemblage of trees, assumed to be capable of cross fertilization, and therefore (for regenerating stands) more genetically related than distant assemblages. "Provenance" is the area of origin of seed.

GENETIC BASE

Species Distribution

Pecan is distributed along the Mississippi River and its tributaries from northern Illinois and southeastern Iowa to the Gulf Coast. Isolated populations occur as far east as southeastern Ohio, northern Kentucky and central Alabama, and as far west as Jeff Davis County, Texas, and Chihuahua, Mexico. The species is abundant on rivers and streams of central and eastern Oklahoma and in Texas west to the Edwards Plateau. Pecan occurs in regenerating stands as far south as Zaachila, Oaxaca, Mexico (Thompson and Grauke 1990).

The geographic and climatic variation across this area is great, as evidenced by data for collection sites in the USDA Pecan Provenance Test (Table 1). In addition, the region includes areas where topography accentuates isolation, and where the environment produces a particular stress . This increases the potential for genetic adaptation within populations across the range (Callaham 1970).

Dispersal By Man

Accurately mapping the native distribution of the pecan is complicated by man's introduction of the species to non-native areas. Even in undisputed native pecan populations, such as the Devil's River area of Val Verde County, Texas, the first recorded occurrence of the species is in association with human artifacts. Pecan seeds and leaves have been archeologically recovered from Baker's Cave in the Devil's River area from strata dated from about 6100 B.C. up to about 3000 B.C.. Pecan has not been reported from excavations of the Golondrina hearth, which is the oldest level of human occupation in the cave and is dated about 7000 B.C.. *Juglans microcarpa*, a riverine

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species like pecan, is recovered from the Golondrina hearth (Dering 1977, Hester 1981; Hester, personal communication). Whether this indicates the introduction of pecan by man between 7000 and 6000 B.C., the natural extension of the range of the species at that time, or is merely a gap in the archeological recovery process has not been determined.

Bettis et al. (1990), reported the presence of a fossil pecan from floodplain sediments of the Mississippi River near Muscatine, Iowa which was accelerator-dated at 7280+-120 yr B.P. They noted that pollen profiles in the Mississippi River Trench indicate higher percentages of *Carya* pollen in the valley than in the uplands during the early Holocene, and suggest that the riverine pecan may be responsible for those peaks. If so, the species was present near the present northern limits of its range as early as 10,300 yr B.P. Bettis et al. (1990) suggest that the abundance of pecan in Early Archaic archeological sites and the co-occurrence of early Holocene *Carya* pollen peaks with the arrival of the Dalton artifact complex in the Upper Mississippi Valley implies early dispersal of pecan by humans.

Pecan populations exist in Zaachila, Oaxaca, Mexico, an ancient ceremonial and administrative center of the Olmec Indians. Valuable information on the antiquity of the pecan population there may be provided by ethnobotanical research in association with the excavation of the site. Unfortunately, no reports are currently available. Pecan has not been recovered from archeological excavations in the Tehuacan Valley (Smith 1967).

Manning (1949) reported that field notes on pecan collections by Dewey in Jaumave, Tamaulipas, suggested introduction of the trees from Texas. Obviously, the older a population is, the harder it will be to retrieve information concerning possible introduction. However, ancient isolated populations, even though introduced, may harbor genetic adaptations to the region.

It is necessary to determine the extent of genetic adaptation to climatic and edaphic variables within native (or long naturalized) populations. Where these populations can be observed to have adaptations to their region, directed selection within the limits of that region should be the most productive approach for rootstock development and may have implications for cultivar development. To accomplish this objective, seed has been collected and provenance tests have been established in Somerville, TX and Byron, GA (Grauke et al. 1989a).

Species Variation Over Range

Nut characteristics in relation to seedstock origin. Nuts collected as seedstocks in the above mentioned provenance tests were studied. Five trees from each of 19 populations (Table 1) were targeted. Ten nuts from each tree were individually measured for weight, buoyancy, length, width parallel to the suture, and width perpendicular to the suture. The nuts were then cracked and kernel weight and shell thickness were determined for each nut. Results indicate clinal patterns of variation in several nut parameters, including shell thickness (which is negatively correlated with latitude) and length to width ratio (which is positively correlated with latitude).

In 1989, nuts were collected from native populations in the U.S. ranging from Illinois south to Louisiana and from Alabama west to Val Verde Co., TX. Ten nuts from each of 5 trees in each population were measured for weight, buoyancy, length and widths. The data on length to width ratios are consistent, with the greatest ratios occurring in the north and east, with the lowest values occurring in the west. Given the strategy of both collections, the data obviously reflect both phenotypic and genotypic responses to variation over the range.

Thompson et al. (1989), reported significant variation in nut parameters of named cultivars from different locations in the U.S, which were attributed to genotype-environmental interaction. Nuts of named cultivars had the highest length to width ratio in Baton Rouge, with reductions in that ratio to the west. Nut length was more greatly reduced in the western populations than was nut width for a given cultivar, which is consistent with these observations. Since the variable of genotype was controlled in these data, the observed variation is phenotypic response.

Nut shape is, therefore, phenotypically influenced by area of origin, with nuts in the north and east being longer in relation to their width than nuts in the south and west. Nut width is evidently more highly conserved under conditions of moisture stress than is nut length. Emergence of pecan seedlings collected in 1989 was significantly related to length to width ratio, with nuts from the north and east being slower to emerge than nuts from the west (Table 2). Whether nut shape has a direct or indirect role in seedling performance (i.e., selective value which could lead to genotypic differences between provenances) or is selectively neutral is unknown at present.

Another nut characteristic which has been associated with seedling performance in this test is percent kernel, which is positively correlated with seedling height and diameter (Fig 1). Variations in percent kernel were not associated with variations in length to width ratios.

Assertions that "small nuts gave as good results as larger ones for nursery purposes" (C. A. Reed, cited in Gray, 1927) or that "nurserymen are justified in using inferior, cheap nuts" (Burkett 1932) are inaccurate. Within a seedstock family, tree vigor has been positively related to nut weight (Hinrichs 1965), and specific gravity (Grauke and Pratt 1985). Between families, seedling performance has been positively related to nut weight (Harris and Tauer 1987), percent kernel (current research), and to less specific criteria of size and fill (Campbell 1978).

Seedling Performance In Relation To Seedstock Origin

Variation in the performance of seedstocks is attributable to several sources. The provenance of the seedstock, parentage, site variability, and culture all influence seedling performance. Clear resolution of the influence of each variable requires control of the other variables, which complicates the research. In some cases, different levels may be controlled (e.g., provenance, pollen parent, pistillate parent) but interpretation apparently oversimplifies results. Hanna (1972) and Madden (1974) worked with the same trees, which were the result of reciprocal crosses between parents representing different provenances. Northern pollen parents reduced the growth of either western or eastern seedstocks. Both researchers found no significant effects of pollen parent on growth of seedlings apart from the effect of provenance or selfing. [Vigor is generally reduced in seedlings arising from a selfed seedstock as compared to the same cross-pollinated seedstock (Romberg and Smith 1946), an example of heterosis.] Madden (1974) concluded that "staminate parent greatly influenced seedling vigor, thus seedlings from open-pollination may be variable depending on the staminate parent". It is more accurate to conclude that the influence of staminate parent is evident in crosses involving northern pollen on either southeastern or southwestern pistillate parents, but that no significant effect of pollen on growth was observed were independent of the north-south provenance effect. Ou (1990) found that northern pollen resulted in delayed germination of southern cultivars of pecan, corroborating the north-south provenance effect by pollen parent.

Early growers found that seedlings arising from southern seedstocks quickly winterkilled in the north, while trees from northern sources performed well (Heiges, 1896, p. 51). The use of Mexican seedstocks in Texas was discontinued based on fear of increased susceptibility to cold injury to seedlings which began growth earlier and ended active growth later than local seedlings (Gray, 1927). Burkett (1932) noted that the longer period of active growth of Mexican seedlings resulted in larger trees, as compared to trees arising from Louisiana and Georgia seedstocks, while seedlings from West Texas were comparable in size.

Phenology of pecan seedlings is, at some level, a function of provenance, with inception and duration of foliation increasing in seedstocks from southern sources. Hanna (1972) observed that the inception of bud growth in the spring varied as a function of both pistillate and staminate parents in reciprocal crosses between cultivars selected from different provenances. Seedlings having either parent from northern provenance began growth later than seedlings whose parents were from either western or eastern provenances. Seedlings of northern parents also significantly smaller than seedlings from eastern or western provenances, with inception of growth being correlated with tree height. If extended phenology is associated with increased size, then southern seedstocks are advantageous, within limits.

The limits to the advantage offered by extended period of growth are set, at least in part, by freeze damage to tender tissues. We have observed phenological differences within open-pollinated families of seedstock which were related to subsequent freeze injury (Grauke and Pratt 1987). Furthermore, scions grafted on families of seedstock with earlier growth were significantly more advanced in growth than when worked on other stocks (Fig. 2), and consequently experienced increased freeze damage (Fig. 3). Under the conditions of our study, no seedlings were killed by the freeze.

Hanna (1972) associated patterns of ion uptake with particular pistillate parents. Seedlings arising from reciprocal crosses were distinguished by ion uptake characteristics associated with the female parent. This lead Hanna (1972) to suggest the possibility of cytoplasmic inheritance. Miyamoto et al., (1985) studied growth and ion accumulation of pecan trees grown in lysimeters irrigated with saline water. They found that 'Riverside' seedling rootstocks absorbed lesser

amounts of Na and produced equal or greater root mass than 'Apache' or 'Burkett' seedling rootstocks. They concluded that 'Riverside' might be better suited as a rootstock in salt-affected areas. We have observed patterns of nutrient accumulation in a test orchard which varied significantly as a function of scion, seedstock and block (Grauke et al. 1989b). The pattern has been consistent for two years. Differences in nutrient accumulation as a function of pistillate parent could be involved in the regional patterns of seedstock performance.

Nuts from our 1989 U.S. collection have been planted in a randomized block test in a greenhouse. Each of four greenhouse benches, bounded by border rows, includes 6 seedlings of each of 53 families which represent 13 populations. Observations have been made on initial emergence and early growth (Table 2). Several points should be noted in these data: 1) Populations of trees can be distinguished from other populations on the basis of days to emergence, height, and diameter, despite variability between families within a population, or variation between seedlings of families; 2) when considered as a group, nursery seedlings made the greatest early growth in height and had the greatest diameters; 3) populations collected in Illinois and Alabama were the latest to emerge and had the least height growth at 54 days; 4) the only nut characteristic significantly related to seedling performance was percent kernel, which was directly correlated with both seedling height (Fig. 1) and seedling diameter.

Our results are consistent, in general, with those of Harris and Tauer (1987), who also found significant variation in the performance of pecan seedlings as a function of the origin of seed, with significant differences occurring between populations. Those researchers collected five seedstocks each of 23 native populations (termed "stands" in their study) in Missouri, southeastern Kansas, throughout Oklahoma, southwestern Arkansas, north Louisiana and north east Texas. Seedlings were grown in a randomized complete block design. Seed characteristics, and seedling growth and phenology were statistically evaluated. They reported differences between populations which were related to north-south clinal trends, with increased seedling size being associated with stands located south of the growing region. Seedling size was positively related to seed size in their test.

These observations reinforce the recognition of distinct "northern" and "southern" pecan regions and imply the potential for selection of distinct, advantageous populations as well as seedstocks within regions. In order to efficiently make directed selections for a particular region, increased resolution of the boundaries between distinct growing regions is needed. In black walnut, for instance, recommended regions for the collection of seed are within precisely delimited geographic units (Deneke et al., 1980). What are the northern extremes to which a given pecan seedstock should be transported from its native range? The northern region accounts for only a small proportion of commercial nut production, with the vast majority of that production coming from native trees. The incentive for the development of appropriate northern rootstocks is therefore less than in the south. However, attention is being focused on the subject (Campbell, 1978; Bill Reid, personal communication).

The east-west geographic limits for the development of rootstocks are more ambiguous than those for the north-south axis. The southern pecan region has historically been divided into eastern and western sections on the basis of climate and associated tree culture, with rootstock being one of many areas of divergence. Gray (1927) offers anecdotal justification for use of western stocks in the West:

> "If Nature, by natural selection, has given the East trees largely scab-resistant, is it not reasonable to suppose that she has also given the West trees that will produce stocks better suited to western conditions? While more evidence along these lines is needed the western planter can scarcely go far wrong by using western stock; and obviously other stocks are not, without more evidence, to be condemned."

These observations are consistent with more recent observations (J. B. Storey, personal communication) of increased tree size and improved performance of 'Western'/'Riverside' sd stions as compared to 'Western'/'Elliott' sd stions, when grown at Delicias, Chihuahua, Mexico. If seedling rootstocks arising from western seedstocks are better adapted to western conditions, what is the basis of that selective advantage? If real differences exist, they should be demonstrable and could form the basis of regional selection criteria.

HISTORY OF ROOTSTOCK DEVELOPMENT

Early efforts to develop orchards by planting selected seed advocated the use of "large nuts with soft shells" (Heiges, 1896, p 50), stressing the "importance of planting only the very best and finest nuts obtainable" (Wm. Nelson, cited in Parry, 1897). These efforts produced orchards with substantial tree to tree variation in nut size, shape and production. Although that method of orchard establishment was soon abandoned, numerous "improved cultivars" were selected from the orchards planted with selected seed in Texas, Louisiana, Florida, and Mississippi (Crane et al., 1937).

The development of vegetative propagation by grafting and budding allowed for increased orchard uniformity, and less emphasis was placed on the quality of the seedstock. Reed (cited in Gray, 1927) traced the early history of nursery seedstock selection:

> "In the beginning of nursery work Texas and Louisiana seedlings, on account of their cheapness and availability, were used. The nuts were usually graded and the larger sizes sold at a profit; the smaller ones being planted. It was found that, apparently, small nuts gave as good results as larger ones for nursery purposes.
>
> As competition increased, nurserymen began to use nuts of improved varieties for seed and make capital of the fact in their advertising. The Stuart nuts, which were chiefly used in the beginning, proved to be slow growers. This practice finally resolved itself mostly into the use of nuts of the Moore and Waukeenah varieties... The actual superiority of these stocks remains yet to be determined..."

In an effort to determine if those stocks were superior, Sitton and Dodge (1938) provide one of the only substantive comparisons of orchard tree performance as a function of rootstock. Using paired trees to reduce variability in initial tree size, they compared the growth and nut production of 'Schley' and 'Stuart' on 'Moore' and 'Waukeenah' seedling rootstocks. Eight year old 'Schley'/'Moore' sd stions made more growth and produced greater yields than 'Schley'/'Waukeenah' sd stions. Seven year old 'Schley'/'Moore' sd stions made significantly greater production than even aged 'Schley'/ 'Waukeenah' sd stions, although differences in size were not significant. 'Stuart' made significantly more growth on 'Moore' than on 'Waukeenah' seedling rootstocks, but yields were so small and erratic that no significance was attached to the concomitant increase in yield. This effort to establish linkage between nursery selections and orchard performance has not been pursued.

Current Practices

The commercial pecan nursery industry currently relies on open-pollinated seed for the production of rootstocks. Selection criteria for commercially used seedstocks are empirically derived by both nurserymen and researchers on the basis of performance in the nursery rather than in the orchard. Variation between different seedstocks is sufficiently great that selections have been made by nurserymen. Selection has been in favor of seedstocks producing vigorous, uniform seedlings (Gray 1927, Traub 1931, Yarnell 1934, Madden and Malstrom 1975, Madden 1976, 1978). Vigorous seedlings are capable of being grafted at an earlier age, reducing the time between planting and sale. Furthermore, since grafted trees are priced by size, uniform vigorous stands require less labor and return more.
The effectiveness of selection for vigor by the nursery industry can be demonstrated by comparison of the growth of representatives of the nursery seedstock to growth of native seedlings collected throughout the U.S. (Table 2). The increased growth of seedlings from nursery seedstocks is confirmation of the high heritability for seedling height and diameter growth calculated by Harris and Tauer (1987).

Seedstock selections made by nurserymen show a stratified geographic distribution (Gast and Overcash 1980, Thompson 1990). In the southeastern U.S., the predominant seedstocks are 'Elliott', 'Curtis', and 'Moore'. In the southwest, the predominant seedstocks are 'Riverside', 'Burkett', and 'Apache'. In the northern pecan areas, native nuts and 'Giles' are largely used (Thompson 1990). Each of these seedstocks originated in the geographic region where it is now used (Thompson and Young 1985), although the original source of the Florida seedlings ('Elliott', 'Curtis', and 'Moore') is obscure (Taylor 1894, Heiges 1896, Blackmon 1926). 'Apache', a controlled cross from the USDA pecan breeding program with both western ('Burkett') and eastern ('Schley') parentage, is used primarily in the region of origin of its pistillate parent.

Root Problems

Little systematic research has been performed to link the criteria of rootstock selection for pecan to production. The lack of attention is due in part to the lack of dramatic problems associated with pecan rootstocks. In the sister genus *Juglans*, root rot caused by *Phytophthora* spp. is the most serious challenge facing walnut growers (McGranahan 1987). There are no comparable widespread, devastating root problems on pecan (Hepting 1971).

Cotton root rot (*Phymatotrichum omnivorum*) is a factor in some areas of Mexico, but occurs only in isolated instances in the U.S. (Brinkerhoff and Streets 1946, Hepting 1971). The lack of severe problems from cotton root rot may be due to the fact that the disease is endemic in Texas within the area of native distribution of pecan, and protection is afforded by the genetic diversity of the regionally selected rootstocks used by the commercial nursery industry. Such conditions should promote the greatest diversity of plant defenses (Harlan 1977).

Nematodes of a potentially new *Meloidogyne* species have been reported on pecan (Johnson et al. 1975, Grauke and Pratt 1985), in each instance associated with observations of differential susceptibility by families of open pollinated rootstocks. The extent of the problem has not been systematically ascertained.

Root problems are so limited in scope and so regional in nature, while rootstock development is such a long-term process, that the most effective strategy may be reliance on the broad genetic base of regionally adapted rootstocks. It follows that one problem to be avoided is the creation of epidemic root problems by undermining the probable basis of current protection -- genetic diversity.

SELECTION CRITERIA FOR PECAN SEEDSTOCKS

Despite the success of the nursery industry in selecting seedstocks appropriate to its needs, some questions remain. Are the needs of the nut production industry, as well as the nursery industry, served by these seedstocks? If so, could the process of selection be enhanced by rootstock research? If production needs are not served by current selection, what is the appropriate criteria of selection?

The ultimate criteria of improved rootstock performance is increased profitability of the orchard. In order for effective selection to occur toward this goal, linkage must be established between seedling characteristics and orchard performance. Screening methods will be established along with that linkage.

Review of the literature reveals ambiguity concerning the interaction between tree size and yield. At the simplest level, increasing size increases yield (Hinrichs 1965, Sitton and Dodge 1938) with the result that mean trunk cross sectional area is the best predictor of tree yield potential. Perhaps more significant are observations such as those by Lutz (1938) who found initial tree size more correlated to subsequent yield than to subsequent growth. The direction of seedstock selection by the nursery industry is consistent with this information. On the other hand is the realization that dwarfing rootstocks could be advantageous (Hanna 1987, Wood 1987). The advantage would be due to reduced tree size, which would allow increased stocking densities, while maintaining adequate per tree production for net increases in per acre production. Whether the goal of reduced size in pecan trees is best achieved by selecting dwarfing rootstocks or by selecting scion cultivars with patterns of reduced growth in relation to stable yields is debatable. Until tests are designed which both control variables of rootstock and cultivar and adequately monitor parameters of growth and components of yield, the debate will generate more heat than light.

Kormanik and Ruehle (1989) reported increased size and performance of sweetgum (*Liquidamber styraciflua* L.) which was related to increased numbers of first order lateral roots (FOLR). Furthermore, seedstock families differed in the production of certain classes of FOLR. These and other reports (Kormanik 1989) suggest FOLR may be a potentially useful criteria to evaluate families of pecan seedstocks. If this selection criteria is found to be useful, it will be consistent with suggestions made by the pecan nursery industry, and incorporated by particular nurseries, over 50 years ago. More importantly, it could serve as a screening tool for large numbers of seedstock families which could improve the power of the selection process.

Another potentially useful selection criteria may be the carbohydrate concentrations of seedlings, within families. Wood (1989) reported that yield in test trees of 'Schley' and 'Stuart' (on unknown seedling rootstocks) was closely correlated with January root starch concentrations. This could be a very useful tool for selection, if families differ in root starch levels and patterns are apparent at an early age.

SUMMARY

The history of rootstock development has been driven largely by the developing technology of "improved orchard culture". The early emphasis on the use of selected seed succumbed, with the advent of vegetative propagation, to the use of undifferentiated or even "cull" seed. Marketing based on the use of known scion cultivars as seedstock lead to the recognition of families of seedstocks which, within each region, could be relied upon for production of uniform vigorous seedlings. This stage of development was reached in the 1930's and little significant change has occurred since. Efforts to establish linkage between nursery selection and orchard performance have not been pursued, despite an increasing body of evidence which justifies the strategy.

The most significant recent development has been the addition of the 'Apache' seedstock to those commonly used by western nurserymen. The development of 'Apache' as a seedstock is an appropriate and almost evolutionary culmination to this period of rootstock development: 'Apache' is a progeny of the prominent western nursery seedstock family of 'Burkett'; it resulted from the USDA cultivar improvement program, but was recommended as a seedstock on the basis of empirical observations of seedling vigor (the selection criteria of commercial nurserymen), without being tested for orchard performance as a rootstock.

The role of research in rootstock development has not been one of insightful leadership. Excellent beginnings have been made, but rather than pursuing tantalizing leads, we have jumped to conclusions. The most common conclusion is that genetic variability of seedstocks is an adversary to be overcome through the development of clonal propagation, rather than an ally to enlist in the development of improved culture. We have often ignored the variable of rootstock family and have almost completely failed to explore the structure of families within populations across the species distribution, within the context of edaphic and climatic environment. As a result, we have overlooked a valuable opportunity to learn of genotype/environmental interactions which have implications, not only for rootstock development, but for cultivar development, for resource conservation, and potentially, for the development of improved management strategies in the face of changing climatic, biological, and economic environments.

Recent reviews of pecan rootstock research (Hanna 1987, Wood 1987) have stressed the need for reliable techniques of clonal propagation. Once achieved, the powerful tool of clonal propagation could be directed toward the development of "dwarfing, nematode resistance, greater yields, precocity of production, selective ion absorption, salinity tolerance, and a reduction in variability of orchard trees" (Hanna 1987). The pursuit of clonal rootstocks is a continuation of the trend of increasing orchard uniformity through the application of developing technology. It is a direction which carries considerable risk for catastrophic disease epidemics (Marshall 1977), even for clonal rootstocks selected for advantageous traits. The risk is increased if "clonal propagation potential" becomes a "major evaluation criteria" (Wood 1987) in itself. Clonal propagation could contribute to the development of durable, efficient rootstocks only if the methods of screening for critical yield limiting parameters are incorporated. The literature indicates that we can control the variable of rootstock sufficiently well to design test systems which will help in establishing rootstock screening methods, while yielding other valuable information on genotype/environment interactions. We should establish a cooperative inter-regional group to design and establish test systems. We might discover that judicious selection for seedstocks will accomplish the goals of tree size control, nematode and disease resistance, increased precocity and productivity, selective ion absorption and salinity tolerance, from a more genetically diverse, and therefore more resilient, base, and within a technology which our industry can immediately incorporate.

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Table 1. Climate indicators for pecan collection sites in the U.S.[1] and Mexico[2]

Mean Site	Location	Lat. (m.)	Long. (cm/yr)	Elev. (C)	Prec. (C)	Temp.	Range
1.	Liv., MO	40	94	213	89	12.4	26.4
2.	Jer., IL	39	91	192	90	11.4	24.9
3.	Ver., MO	38	94	226	100	13.9	25.6
4.	Web., KY	38	88	125	111	13.8	25.1
5.	Cow., KS	37	97	347	80	14.6	25.7
6.	Chr., KS	37	95	274	100	14.3	25.6
7.	Lak., TN	36	90	94	122	14.8	26.1
8.	Bow., TX	34	94	119	113	17.1	22.7
9.	Wsh., MS	33	91	39	132	17.4	23.0
10.	T.G., TX	31	100	580	46	18.7	21.1
11.	V.V., TX	30	101	313	44	21.0	19.1
12.	Gon., TX	30	97	95	98	19.8	19.2
13.	Kin., TX	29	100	227	54	21.9	19.0
14.	Zav., TX	29	100	341	54	21.0	19.8
15.	Jau., MX	23	99	884	75	24.4	11.8
16.	S.C., MX	22	100	1219	36	17.9	7.8
17.	Ixm., MX	20	99	1829	39	14.2	4.3
18.	Say., MX	20	104	1372	90	19.1	8.0
19.	Oax., MX	17	97	1737	64	20.6	5.1

[1] Anonymous. 1986. Climatological data. Annual Summary (by state) NOAA.

[2] Garcia de Miranda, Enriqueta and Zaida Falcon de Gyves. 1980. Nuevo Atlas Porrua de la Republica Mexicana. 6th ed. Editorial Porrua, S. A., Mexico.

Table 2. Population effects pecan seedling emergence, height and diameter.

Population	Location (days)	Emerg.[z]e	Ht.[y] (cm)	Dia.[x] (mm)
Ala	Demopolis, AL	18.2a[w]	23.8 g	3.24 de
Ill	Greene Co., IL	17.9a	22.8 g	3.25 de
Lou	Gulf coast, LA	16.6 b	27.1 de	3.41 cd
Okl	S. Cent. OK	16.2 b	26.4 ef	3.26 de
Nur sdstk	Various	14.9 c	35.2a	4.26a
Bra	Brazos R., TX	14.8 c	29.3 cd	3.42 cd
Scu	Scurry Co., TX	14.4 cd	26.7 ef	3.18 e
TGr	San Angelo, TX	14.2 cd	26.4 ef	3.30 de
Nue	Nueces R., TX	13.7 de	29.5 c	3.58 c
Dev	Devil's R., TX	13.7 de	29.0 cd	3.24 de
LMo	Las Moras, TX	13.6 de	28.4 cde	3.29 de
SFe	Del Rio, TX	13.6 de	32.2 b	3.67 b
Cha	Champion, TX	12.8 e	24.7 fg	3.18 e

[z] Days from planting to first emergence from soil.

[y] Height measured 54 days after planting.

[x] Diameter measured 55 days after planting.

[w] Mean separation in columns by Duncan's multiple range test, 5% level.

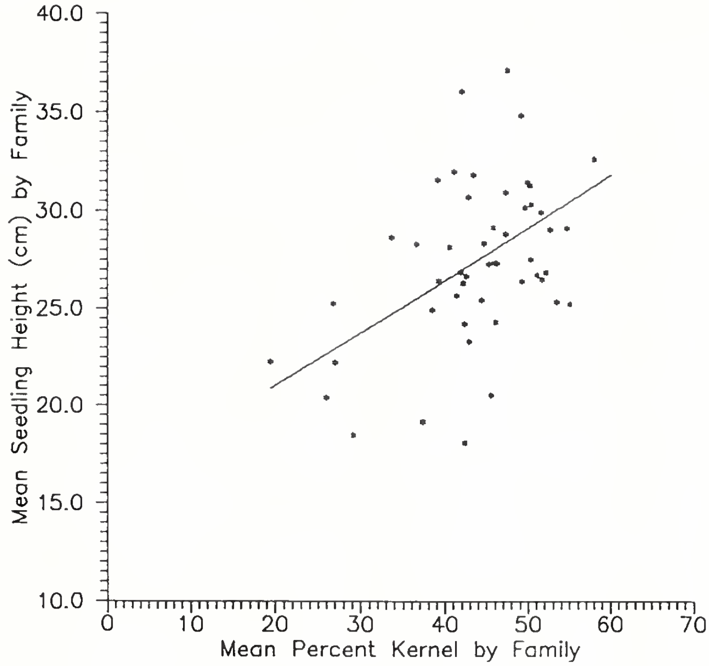

Figure 1. The correlation between mean nut percent kernel by family and mean seedling percent height by family for 53 families of open-pollinated pecans.

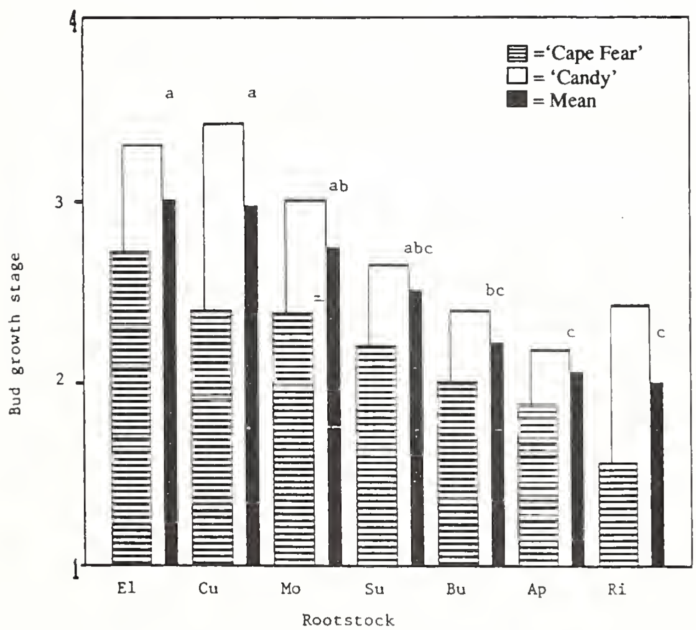

Figure 2. The effect of rootstock on inception of bud growth of grafted pecan trees. Means separated by Duncan's multiple range test, 0.05 level. Bars having the same letter cannot be separated.

TISSUE CULTURE OF PECAN

I.E. Yates[1]

Plant tissue culture had its origins in the 1930's as an academic endeavor to understand developmental mechanisms in plants. As true with other areas of plant science, the objectives of plant tissue culture have evolved, in many cases, to product-oriented goals. Examples of plant tissue culture techniques being explored for commercialization are micropropagation; generation of genetic variants either through tissue culture alone or in conjunction with gene transfer technologies; encapsulation of somatic embryos for seed dispersal; germplasm preservation; and production of plant secondary metabolites for use in the pharmaceutical, food-processing, and pesticide industries (Bock and Marsh 1988). Most research in pecan tissue culture has focused on either micropropagation or development of genetic variants and this paper is a review of these two subjects. The products generated through tissue culture in the 1990's can be expected to increase as progress is made in the refinement of the basic technologies.

MICROPROPAGATION

Micropropagation is a term usually restricted to the mass propagation of clonal plants in culture; i.e., the production from a single plant part of numerous plants each being genetically identical to the mother tissue. One of the most common methods of micropropagation is to force a bud, either excised from or still attached (nodal segment) to the stem, to produce many shoots instead of only one. The shoots are then treated with hormones to induce rooting.

Micropropagation was the first area of plant tissue culture to be of commercial value. The orchid industry was one of the commercial enterprises to benefit first from the commercial applications of micropropagation. Prior to the 1960's, conventional vegetative propagation techniques for orchid production were very slow. In a series of orchid tissue culture studies designed to eliminate viruses, the relatively short time required for the generation of clonal orchid plants was realized quickly (Rao 1977). This caused a revolution in the orchid industry. By 1984, there were over forty companies in the U.S. and many others throughout the world specializing in orchid production *via* micropropagation (George and Sherrington 1988). This and other success stories, primarily with ornamental plants and a few vegetable crops, led to the concept that thousands of clonal plants of any given plant species could be obtained within a few months by excising the appropriate plant part and providing the excised plant part with the appropriate balance of phytohormones.

Skepticism is mounting that plants generated *via* micropropagation can be considered to possess absolute clonal fidelity because somaclonal variation is known to occur (Scowcroft and Larkin 1988). The term somaclonal was coined originally to describe all plants arising from the same initial piece of explant material. It was assumed that all plants would be genetically identical; however, this may not be true, even for plants in which there is no intervening callus phase. Hence, the term somaclonal variation evolved. However, the following discussion is written on the premise that micropropagation will preserve the genetic identity and integrity of the mother tree as faithfully as conventional propagation techniques.

Advantages in Micropropagation of Pecan

Micropropagation of pecan would be advantageous for rapid clonal multiplication and germplasm preservation. Rapid clonal multiplication would be useful in studying elite pecan trees with desirable characteristics and rootstock influences on tree productivity. For example, hundreds of plants could be produced within a few months from a seedling tree selected for resistance to insects or diseases. These plants could be tested at different geographic locations to determine whether the characteristics of interest remained constant under various climatic, insect and disease pressures. Likewise, micropropagation could provide genetically identical plants for investigating the control by the rootstock on tree productivity.

Another advantage in being able to micropropagate pecan would be for germplasm preservation. Techniques for the integration of micropropagation

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with germplasm preservation usually involve cryopreservation of buds that are then regenerated to plants as needed or, alternatively, maintenance of culture stocks on medium that dramatically reduces the growth rate so that infrequent transfers are required. With cryopreservation techniques using liquid nitrogen, up to four buds from each of 684 trees could be stored in a tank 5 feet in diameter and 2 feet in height. Considering there are over 1,000 named pecan cultivars (Thompson and Young 1985) and untold numbers of seedling sources, maintenance of the tremendous genetic variability that exists in the population of pecan in the U.S. by conventional field propagation techniques is a forbidding task. Even through tissue culture, such a task would be unreasonable. However, the percentage of the available types that could be maintained would be increased. The dollars saved over tree maintenance in the field would be impressive.

Advances in Pecan Micropropagation

The first reported attempt at tissue culture of pecan was not until the late 1970's (Smith 1977, Smith and Storey 1977) fairly recent when considering the science of woody plant tissue culture began more than 50 years ago. Smith and Storey (1977) cultured seedling pecan stem segments on a variety of media formulations. Callus was initiated and one or two spontaneous roots and/or shoots were produced using IAA and kinetin in relatively low concentrations (0.75 to 1.1 ppm IAA with 1.1 ppm kinetin for roots, 0.75 ppm IAA with 2.0 ppm kinetin for shoots). Best growth of callus was between 0.5 to 1.0 ppm IAA and kinetin. Knox and Smith (1978) produced a shoot and root in tissue culture, but technical details were not defined. Knox (1980) described obtaining plants by culturing nodal segments from 'Riverside' seedlings first on medium containing 0.1 to 0.7 ppm IBA and 0.1 to 2 ppm BA followed by culturing on 1 ppm IBA and 1 ppm phloroglucinol. Wood (1982) reported the first successful multiple shoot proliferation from nodal segments. Hansen and Lazarte (1984) described obtaining roots on shoots multiplied in culture. In order to circumvent the problems of contamination as described by Wood (1982), zygotic embryos were dissected from the developing fruit and germinated *in vitro* for multiple shoot proliferation (Yates and Wood 1989, Ou 1989). Rooting of multiple shoots generated in this manner was accomplished (Ou 1989).

All the work discussed to this point centered around tissues obtained from seedlings or seeds. Any plants regenerated from these tissues would have a new combination of genes. To be of more immediate commercial application, propagation would be more beneficial from mature pecan trees in which characters of interest have been demonstrated. Plants regenerated through multiple proliferation from buds or meristems would have the same characteristics as the mother plant. Thereby, the 15 to 20 years required to evaluate field performance for pecan plants that contain unknown characteristics could be eliminated. Pecan trees that are 10 to 15 years old may appear to have desirable crop production characteristics, but as the trees reach maturation after 15 to 20 years growth, fruit quality may become unacceptable (Sparks 1990). Thus, plants developing from cross-pollinated seeds or any tissues thereof must be subjected to decades of field tests.

Cotten (1983) attempted to obtain *in vitro* multiplication of shoots from buds of mature pecan trees; however, this study was hampered by contamination and the exudation of phenolics from the explant during culture establishment. Phenolics were reduced by adding charcoal to the medium and incubating the cultures in darkness. Treatment of explants with 70% ethanol for 8 min, then with 0.525% sodium hypochlorite for 15 min followed by a 4.5 hr soak in a saturated benomyl solution was more effective than using antibiotics to control contamination. Even though parameters were optimized for culture establishment, no plants were obtained in these studies.

Recently, plant regeneration has been achieved by axillary bud proliferation of nodal stem segments taken from mature trees (Dr. Gregory Phillips, Department of Agronomy and Horticulture, New Mexico State Univ., Las Cruces, personal communication; Corte-Olivares 1987). However, contamination was a major problem during culture establishment in this study and only an average of one shoot/explant was produced. In our laboratory, we have utilized techniques similar to that used for walnut which involves washing the shoots for 4.5 hr in running water prior to inoculation into culture medium (McGranahan et. al. 1988a). However, with field material collected in the southeastern U.S., such techniques are not stringent enough to eliminate gross contamination of cultures.

In summary, micropropagation of pecan has been achieved with tissues from both juvenile and mature trees. However, more work is required before large numbers of trees can be generated rapidly and repeatedly through these procedures.

Novel propagation techniques will be required to successfully micropropagate pecan from mature trees.

Difficulties in Micropropagation

The principle of micropropagation is simple. However, putting these principles into practice for pecan is not so easy, especially using tissues from mature wood. Micropropagation of seedling material less than one-year-old has been successful in the laboratory, but no plants have been hardened off to grow in the field or even in the greenhouse. There are two major problems encountered in the micropropagation of pecan from field-grown material. One is contamination of the plant cultures with microorganisms, and another is the recalcitrant nature of pecan *in vitro*.

Even though developing repeatable micropropagation techniques for pecan has been slow, so has the progress with trees in general. The protocol suitable for herbaceous plants is not directly applicable to woody plants, especially species of forest and nut trees. Although over five decades have elapsed since the pioneering plant tissue culture studies with tree species in the 1930's (Gautheret 1934), there are still no commercially micropropagated forest tree species in the U.S. (Hanover 1987). This serves to highlight the technical difficulties of establishing, maintaining, and manipulating cultures of tree species. As a result of the long-term commitment required to surmount these difficulties, the interest and financial support for developing micropropagation methods for woody plants is waning (Mezitt 1988).

There are several problems that have limited progress in micropropagation of pecan, as well as many other tree species. These problems include: 1) obtaining appropriate explant material; 2) contamination of explant material; 3) release of toxins from the explant in the medium; 4) low shoot multiplication rates; and 5) poor or no root formation. The first three problems may be encountered during culture establishment.

Due to the nature of the annual cycle of growth, obtaining the appropriate plant part to initiate a culture may be possible for only a few weeks or even a few days out of the year. For example, anthers in pecan are produced on an annual basis and are at the appropriate stage for tissue culture for only a few days. Therefore, the supply of experimental material seriously limits the scope of possible investigations. Another common difficulty is establishing aseptic cultures; i.e., cultures with only one organism growing. With the objective to micropropagate an elite pecan tree selected for its field performance, axillary bud proliferation would be a theoretically suitable methodology. However, such tissues may be difficult to establish in culture because field-grown plants frequently harbor fungi and bacteria which are difficult to eliminate. Stringent surface sterilization procedures used on the explant to reduce the growth of these contaminants in culture may reduce the viability of the plant tissue (Knox 1980). To avoid this problem, antibiotics which are specific for the contaminants may be added to the medium. Such an approach has not been successful in pecan (Cotten 1983). Another problem often encountered in culture establishment is that on excising the explant from the source plant, the injury response generates production of toxins which are detrimental to the growth of the plant tissue (Graves et al. 1988). This response may be partially alleviated by treating the explant with chemicals to retard oxidation processes, using a large explant initially and removing deteriorating portions every few days during culture establishment, or transferring the explant material to fresh medium as discoloration increases. Extensive browning of tissues, as well as diffusion of these chemicals into the culture medium, may retard or prohibit the growth of the explant tissue.

Once culture establishment has been achieved, the next challenge is the activation of growth of the appropriate plant part at the appropriate site on the explant. The appropriate stimuli for shoot elongation and multiplication must be provided *via* culture medium and environmental conditions. Once shoot multiplication has been attained, producing roots on those shoots is another hurdle.

Finally, acclimatizing plants generated *in vitro* from the nutritive conditions in the culture medium to soil conditions is difficult. Survival rates have been low when converting pecan plants regenerated *via* tissue culture techniques from the conditions in the culture vessel to soil conditions. Consequently, accumulating enough plants at any one time to conduct meaningful experiments to determine the appropriate protocol for hardening off plants has not been accomplished. We do have a few plants in the greenhouse that have been carried through tissue culture, but not in a large enough quantity from any one experiment to be able to give definitive techniques for establishing protocol.

GENERATION OF GENETIC VARIANTS

Genetic variability *per se* would not appear to be a primary objective for pecan tissue culture. With over 1,000 named cultivars and millions of seedlings existing in the wild, we do not have the facilities for preservation of the genetic variation already existing. Seedlings surviving in nature probably have much adaptive conditioning already inherent in their genome (Sparks 1990). Association of this variability in the proper combinations by directed gene transfer is the primary value of this area of plant tissue culture for pecan. A seedling pecan tree or cultivar may exist that has appropriate adaptive growth characteristics for the environmental niche in which it has survived thus far (Sparks 1990). However, one or two characteristics may be lacking that could improve crop production. For example, 'Desirable' produces a nut that brings a good price, alternate bearing is minimal, but early fruit maturity would enhance marketability. Identifying the part of the genome responsible for early fruit maturity in another cultivar or seedling selection and transferring this to 'Desirable' would produce a highly profitable cultivar for the southeastern U.S. (Sparks 1990).

Improvement of Pecan through Genetic Variation

Techniques of pecan tissue culture have been developed that will provide for the application of directed gene transfer for pecan tree improvement. One factor responsible for this is the ease with which somatic embryos can be generated from pecan tissue culture (Laird 1985, Yates and Corte-Olivares et al. 1990, Yates and Reilly 1990). Somatic embryos are different from zygotic embryos. Zygotic embryos are produced by the classical reproductive scheme of the union of the egg and sperm. "Soma" is the Greek word for body; hence, somatic embryos originate from body cells, not reproductive cells.

Developing techniques for somatic embryogenesis in pecan has proven to be a much easier system of plant culture to manipulate than micropropagation from stem segments. One reason for this is that establishing cultures free of microorganisms is not a problem. In most cases, the initiating tissue is derived from the developing nut. In our laboratory, the protocol is to soak the fruit (husk and ovary) in 70% ethanol for 20 min. Subsequently, the husk is discarded and the embryonic tissue is placed in culture. This tissue is already in a metabolically active mode to form cotyledons so that activation of growth is not a problem. Thus, both the problem of contamination and of growth activation encountered in micropropagation techniques are circumvented. Somatic embryos are expected to be useful in directed gene transfer. McGranahan et al. (1988b) have been able to utilize walnut somatic embryos to demonstrate direct gene transfer. Such techniques should be directly applicable to pecan since the vehicle used to infect walnut embryos is *Agrobacterium*, the organism responsible for crown gall in pecan roots. Directed gene transfer experiments are currently in progress with pecan.

Difficulties of Introducing Genetic Variation into Pecan

In the early 1970's and 1980's, immediate commercial gains by the methods of biotechnology were considered to be achievable for plant improvement within a few short years. A quote by Wilson and Sullivan (1984) in Economic Review reflects the optimism inherent in those times: "Civilization may stand on the edge of a biotechnological revolution that could affect virtually every area of the environment". These authors predicted that a number of plants with minor improvements could reach the marketplace by 1987 and plants with significant genetic alterations would be commercially available by 1990. These predications have not come to fruition.

Independent commercial biotechnology companies were formed with the view of becoming profit-making enterprises. Companies with names tying their production objective to genetic engineering (Genetex, Calgene, and Agrigenetics) were formed. Agrichemical companies such as Monsanto and Dupont invested large amounts of capital to establish in-house research programs in biotechnology. Established companies not setting up their own in-house research programs financed research through biotechnology companies. For example, Kellogg, a major food processing company, invested $10 million in Agrigenetics Corporation in 1982 (Wilson and Sullivan 1984). For this investment, Agrigenetics was to develop strains of oats, rice, and wheat with high protein content and minimize fertilizer requirements for the growth of these plants. The financial returns expected by Kellogg did not materialize. Important results on the molecular biology of these organisms did emerge, but the outcome was still at the purely basic biology level and not of commercial application.

The priorities set by the Agriculture Research Service in the mid-1980's are other examples of the optimism that biotechnology was going to be a quick fix for developing superior plants. A brochure entitled "Solving Agricultural Problems with Biotechnology" was issued. In this brochure, yearly ARS funds of $26.7 million were identified as being directed to biotechnology, and a long-term commitment to biotechnology was emphasized. By the late 1980's, skepticism of the immediate commercial exploitation of this science became apparent as funds were redirected to other research priorities.

The application of genetic engineering to pecan, as well as other plant species, has been hindered by two major problems. One is that isolation of the desired genes has been limited because the biochemical or genetic basis of the phenotype is unknown. Another is that plant cells are much less amenable than animal cells to molecular biology studies. The restricted adaptability of plant cells for molecular studies is due to two parameters. One is that plant cells have a cell wall which restricts the introduction of foreign materials into the cell. The other is that genetic analysis is complicated because some plant characteristics are controlled outside the nucleus by chloroplast and mitochondrial genomes.

In summary, the immediate need for genetically engineering pecan trees is to conduct fundamental studies on biochemistry and molecular biology. These studies are necessary to identify genes determining the phenotypes of characteristics considered desirable in a commercially productive pecan tree. Important genes then may become targets for genetic engineering. In addition, information on the regulation of gene expression will be required in order to know how to turn these genes on and off in the right place at the right time. The belief is still alive that the timing and extent of plant developmental processes such as flowering, seed formation, ripening and senescence may one day be changed through genetic engineering (Grierson and Covey 1988).

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PECAN TREE SPACING AND TREE SIZE

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Pecan trees have no known upper age limit for production; therefore, trees may grow to enormous size and still remain productive. Approximately 15 cm of new growth is added to the ends of limbs annually, and they continue to grow until lightning, shade, disease or limb breakage limit their growth. Trees sometimes exceed 30 m in height and limbspread. Trees of this size would be crowded at more than 11/ha.

Early plantings were usually spaced at 30 trees/ha while recent high density plantings have exceeded 120 trees/ha. At these spacings overcrowding is eventually inevitable unless a program of tree thinning or size control is practiced.

One of the earliest papers on pecan pruning was given by C.A. Reid (1923). Reid described some pruning studies that had been started in Thomasville and Albany, GA, but gave no data. Principles of pruning which he described, however, are still important today. These are: (1) Prune trees when transplanted and during formative years to train and shape them to a central leader system. Prune only to assure symmetry and balance; (2) prune back one branch of a fork so that it will be a side branch; (3) in the adult stage, prune only enough to permit free air circulation and let light through the tree, and to permit balance; and (4) In old trees, prune back main leaders as much as needed in one year and shorten smaller branches the following year. Later Crane and Dodge (1932), presented additional principles: (1) Prune trees to a modified central leader system, because of such advantages as a low and spreading tree and a head made up of a large number of main branches which grow uniformly with freedom from weak crotches; (2) pruning has a dwarfing influence. Pruned trees or pruned branches will be smaller than they would have been had they not been pruned. The removed wood is never completely replaced, but some limbs may be stimulated to grow more than others; (3) pruning stimulates the vigor and length of the new growth. Pruning may be used to stimulate orchards of low vigor and poor growth; (4) the growth responses following pruning are localized. When a branch is cut off the stimulation of growth occurs near the pruning wound. Removing a limb on one side of a tree has little effect in stimulating growth on the other side; and (5) heading back tends to stimulate wood growth while thinning out promotes fruiting.

Pruning should be done in the dormant season. Summer pruning tends to devitalize the tree, because it removes leaves which have been formed at the expense of stored food materials and are cut off before they have completely built back the carbohydrates which were used in their production. In no case should a short stub be left (Crane and Dodge 1932).

Crane and Dodge (1932) state that, in general, pruning of bearing pecan trees should consist primarily of thinning out with sufficient heading back to control length of some particular limbs or the height of the tree as a whole. An ideal tree has been described as one that has a low spreading top with strong main scaffold limbs which are well-distributed on the trunk and with the fruiting wood evenly distributed throughout the top (Crane and Dodge 1932).

The first results of studies of pecan pruning that I have found were those reported by Reid (1924) where he refers to a study by DeWitt which showed that where one branch was removed, two grew in its place and the top of the tree was more shaded than before. Reid reported that one year's research on pruning old Frotscher trees showed that where large or small cuts were made, the new growth was at the immediate points where cuts were made. No data were given in this report.

Crane (1932a and b) reported that prior to 1929 there were no data available on pecan pruning. He did not mention the report cited earlier by Reid. He reported on two years of a study started in 1929-30 and gives the first data available on pecan pruning. He compared unpruned, unfertilized trees with pruned unfertilized and pruned fertilized trees. Trees were 'Stuart' planted in 1915. He did not describe the method of pruning used, but implications are that it was some type of thinning-out. Pruning gave increases in trunk cross sectional area, increases in terminal growth and increases in nut size but did not affect yield and had little effect on kernel quality. A later report on the same study (Crane 1933) stated that

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pruning produced longer and stockier new shoots and increased the number pistillate flowers on weak shoots but not on strong shoots. Pruning stimulated more vigorous shoot growth, which increased nut set and reduced the amount of nut drop. Total yield, however, was not affected, but nuts from pruned trees were better filled. Pruning also improved spray coverage and reduced cost of spray application. A later report (Crane and Hardy 1934) added that pruning of 'Stuart' increased the percentage of large sized nuts, specific gravity, kernel wt. and percentage fill. A similar study with 'Pabst' also increased nut size but had little effect on specific gravity, kernel wt. or degree of filling.

Early pecan pruning studies were of insufficient duration to reach conclusive results. These studies (Crane 1932a and b, Crane 1933, Hardy 1947) reported increases in nut size from pruning, but few reported increases in yield from pruning old trees (Crane 1932a and b, Crane and Dodge 1932, Crane et al. 1935, Hardy 1947, Reid 1923, Reid 1924). Yield was not affected in some cases (Crane 1932a and b). Pruning increased growth of remaining limbs which increased nut set and reduced nut drop (Crane 1933, Crane and Dodge 1935).

A report from Oklahoma (Anon. 1967) indicated favorable results from pruning 'Western'. Trees were apparently 12 years old and were pruned for 1, 2, 3, or 4 years. Pruning increased yield, nut size, leaf size, leaf green color intensity and shoot length. The type of pruning was not described.

There are many different types of pruning, and they should be specified when discussing pruning. Thinning-out removes an entire branch or limb while heading back removes only part of the limb. It is still rather nebulous where these two pruning practices overlap. The selective limb pruning that we have been doing would be considered thinning out since an entire limb is removed back to another limb; however, it does reduce the tree height or head it back to a great extent. "Dehorning" and hedging would be considered types of heading-back. In these cases a stub is left from which regrowth may occur.

The following are some reports of studies dealing with different types of pruning:

"Dehorning"

"Dehorning" is the most severe type of heading where large limbs are cut back leaving several stubs. Early work showed that where large limbs were cut back to stubs the tree was taken out of production for several years. Many vigorous watersprouts grew near the cut and often caused more shading than before pruning (Reid 1924).

In 1932 an orchard of 24-year-old 'Stuart' spaced 14.2 x 14.2 m was either heavily pruned or thinned on the diagonal (Crane et al. 1934). Heavy pruning consisted of cutting about 1/2 the tops out the spring of the first year with subsequent light or corrective pruning and some heading back of long branches. Unpruned and unthinned control trees were left. This type of heavy pruning reduced growth in trunk cross sectional area and greatly increased terminal shoot growth for the 2 years reported. No nuts were produced on pruned trees the first year. Yield for the next two years was only 0.4 kg/tree for pruned trees compared with 6.0 kg/tree for thinned trees. Pruning in this manner was thus disastrous; however, nut size was greatest for pruned trees. They concluded that thinning the stand is the only treatment that shows commercial possibilities.

Later Arnold et al. (1981) dehorned old trees at 5.5 m and attempted to increase yield by follow up hedging. Neither the dehorning nor dehorning + follow up hedging was satisfactory. Both treatments reduced yields drastically. The increased terminal growth from both dehorning treatments was temporary.

Light Heading

A less severe type of heading than "dehorning" was used in the late sixties in Texas (Storey et al. 1970; Hooks and Storey 1971). The study compared heading of new growth with applications of the growth regulator Alar (daminozide). The heading treatment consisted of removing 25% or 50% of the randomly selected branches in 1966 and 1967. Cuts were 6 to 8 cm in diameter. Heading also increased, growth density, leaf color, precociousness, nut specific gravity, % fill, % kernel, % fancy nuts, nut size, and kernel grade. Heading decreased trunk growth, shuck disease, yield, nuts/kg, and % standard and amber nuts. Yield was decreased by 18 kg by heading.

One attempt to increase production by high density planting and pruning in Arizona was reported in 1970 (Kuykendall et al. 1970). Heading-back (removal of 1/3 of buds) of vigorous unbranched shoots of 4-year-old 'Western Schley' trees in the dormant season increased yield over unpruned trees by 50%. Dormant heading of vigorous branches reduced the number and length of new

lateral shoots. Heading increased the number of new shoots that fruited the next year (Kuykendall et al. 1970).

Responses to tip pruning or light heading are apparently less for cultivars of eastern origin than those of western origin. Overcash and Kilby (1973) did pruning similar to Kuykendall on 9-year-old 'Desirable' and 'Stuart' trees. They compared light pruning (145 cuts/tree of 19 g/cut) with heavy pruning (295 cuts/ tree of 39 g/cut for 'Desirable' and 214 cuts/tree of 45 g/cut for 'Stuart') with no pruning. Two years of heavy pruning reduced tree size and yield. Percentage kernel was not affected by pruning. They concluded that only corrective pruning and tree training should be done.

Hedging

Hedging is a mechanical form of heading whereby all limbs growing beyond a specified plane are removed at the point where they intersect the plane. Much interest in hedge pruning came about in the 70's after the practice was adopted by Stahman farms without the benefit of positive results from research. Most of this type of pruning was done on 'Western Schley' which was probably a cultivar best suited to hedge pruning since it bears on interior limbs. Malstrom and Haller (1980) compared hedge pruned vs unpruned 'Western' trees and concluded from early results that hedge pruning was feasible and desirable once trees begin to crowd. Their pruned tree yields were reduced slightly the first year, but nut quality and light penetration were practically the same for both pruned and unpruned trees. Smith and Hinrichs (1980) hedged 9-year- old 'Western' trees spaced 5.3 x 5.3 m to a 1.8 m width in Oklahoma in 1971 and topped at heights of 3.0, 3.7, 4.3, 4.9, 5.5 and 6.1 m in 1972. The largest crop of 980 kg/ha was produced in 1970 before hedging in 1971. Good crops were produced in 1972, 1973, 1974 and 1977. Alternate bearing was apparent with two "off" years between 1974 and 1977. No yield exceeded that of 1970. Trees became overcrowded at 12 years of age. Production increased as pruning height increased to 5.5 m. More scab and depredation from blue jays occurred at the closer spacing.

Hedge pruning of 17-year-old 'Western' trees spaced 9.8 x 9.8 m apart for three years did not markedly alter production or nut quality but did increase light penetration into the orchard (Malstrom 1981). In another study 'Western' trees spaced 4.9 x 9.8 m were either hedge pruned or thinned. Thinning increased yield/tree over hedging, but hedging increased yield/ha over thinning (Malstrom 1981). Mechanical pruning of pecan trees did not induce lateral branching (Malstrom and McMeans 1977a).

In Georgia, 'Elliott', 'Farley', and 'Desirable' trees were hedged on each of the 4 sides and top over a 5-year period (Worley 1985). Approximately 1/8 of the bearing limbs were removed with each side hedging and 1/2 was removed with top hedging. Hedging drastically reduced yields, particularly in the year after the top was removed. Overall yield for the 8-year-period was reduced for 'Desirable' and 'Farley'. Hedging threw 'Elliott' out of phase with the alternate bearing cycle so that hedged trees produced more than the control and less than the control in alternating years, and the overall yield was not reduced significantly. Hedging reduced nut volume but had no significant effect on nuts/kg count. It increased terminal growth slightly but had little effect on circumference growth.

Tip Pruning

Tip-pruning is a system of light annual pruning, beginning at an early age, in which less than 15 cm of all terminal shoots are removed. The objective of tipping is to force buds equally along the length of the limb and, in effect, to divide the vigor among a large number of shoots and enhance yield increases at an early age (Puls et al. 1976b). Dormant tip pruning and summer tip-pruning were equally effective but foliage made summer tip-pruning more difficult (Puls et al. 1976b). Tipping or heading-back during the growing season (summer pruning) induced production of new lateral shoots (Kuykendall et al. 1970).

Tip pruning increased lateral shoot development of 'Cherokee', 'Chickasaw', 'Western', 'Apache', and 'Caddo' but did not increase lateral shoot development of 'Mahan', 'Mohawk', 'Shawnee', 'Tejas', and 'Cheyenne' (Puls et al. 1975, 1976a and b). Removal of 1/2 the previous season's shoot which simulates hedging reduced lateral shoot development below that of the control (Puls et al. 1975, 1976a and b).

Selective Limb Pruning

With selective limb pruning the entire limb is removed back to another limb without leaving a stub. The objective of selective limb pruning is to have the energy that would have gone into the pruned-off limbs redistributed to the remaining limbs. Sparks (1988) has shown that some redistribution does occur by pruning off all other branches of limbs supporting 4 and 8 cm 1-year-old

shoots. Pruned limbs had greater shoot growth and shoot vigor, more pistillate flower production and less pistillate flower abortion on the remaining twigs than did unpruned limbs.

Crane and Dodge (1935) reported on a study where 10-year-old 'Schley' trees were pruned by detailed thinning out of weak shoots so as to open up the center of the tree in 1931 and keeping it open in subsequent years. Approximately 4.5 kg of wood was removed per year. Pruning stimulated shoot growth but did not affect trunk growth. Pruning also increased blossoming and nut set/shoot, but nuts/cluster were not affected.

We initiated several selective limb pruning studies in an attempt to find a practical method. We knew that a feasible pruning system would have to be one that removed relatively small amounts of wood at one time and one that was labor efficient. Selective limb pruning fit these requirements. In one study of pruning height (Worley 1987), one to three limbs/year were removed at their junction with another limb at a height below 9.1 or 12.2 m. Approximately 1/8 of the top was removed the first year. These 2 heights of pruning were compared with no pruning. Trees were large 'Stuart' (>50-years-old) spaced 21.3 x 21.3 m and had not begun to crowd. Pruning increased shoot growth, vigor and color rating, nut size, and in dry years it increased percentage kernel and kernel grade. Pruning reduced yield, particularly in dry years. Trees were so large that some limbs >30 cm in diameter were removed early in the study in order to meet treatment specifications. In another study of pruning intensity (unpublished) on similar trees, we removed either 1, 2, or 3 limbs/year from the top to a lateral below a height of 9.1 m. In this study yields were not reduced by the removal of one limb/year. The other advantages of pruning such as larger nut size, longer shoot growth, and better tree appearance were obvious. In another old overcrowded and low producing 'Stuart' and 'Schley' orchard (>50-years-old) selective limb pruning removed approx. 1/4 of the limbs on alternating diagonal rows in only one year. Yields of adjacent pruned and unpruned trees did not differ for the next two years, and both produced good crops the year after pruning. Where neither pruned or unpruned trees were bearing prior to pruning, both pruned and unpruned trees were bearing after alternating rows were pruned (Worley 1978). Apparently the pruning opened the interior of the trees enough to allow light to both pruned and unpruned trees.

In another study on approx. 20-year-old trees spaced 14 x 14 m, we removed 1-3 limbs/year at the junction of another limb below 9.1 m so as to leave no stub. Selective limb pruning reduced yield of 'Elliott' but did not significantly affect overall yield of 'Desirable' or 'Farley'. In one year, selective limb pruning doubled yield of 'Desirable'. Selective limb pruning increased nut volume and sometimes increased terminal growth and decreased nuts/kg count (Worley 1985).

Similar studies in Texas (Managan et al. 1984) did not show yield or quality increases over the control from limb removal the first year, but specific leaf wt. was increased by limb removal. In an Arizona study, thinning out vigorous "crow's feet" of 4-year-old 'Western Schley' trees in the dormant season increased yield over unpruned trees by 50% (Kuykendall et al. 1970).

In 1944, 'Moore' trees were pruned in the "off" year (1944) or the following "on" year or not pruned (Hardy, 1947). Pruning was a general thinning-out with some heading-back. Data taken for three years showed no effect on yield, but nut size was increased by pruning. There was no net increase in circumference growth of pruned trees relative to the check.

Spacing

Crowding can be prevented or reduced by (1) dwarfing rootstocks; (2) regulation of fertilizers; (3) pruning; and (4) use of growth regulators (Malstrom and McMeans 1977b). We should add to this list the proper spacing and timely thinning of trees. Dwarfing rootstocks are not currently available. Regulation of fertilizer must be limited to that providing proper nutrition to the tree. Results from most pruning tests have not been encouraging, and there are no currently registered growth regulators. Problems with registration and bad publicity make it unlikely that growth regulators will be used to any great extent in the near future. Tree spacing then appears to be the best solution to overcrowding.

Pecan tree spacing has received much discussion but comparatively little research. Much interest was developed in high density plantings in the 60's and 70's, and many were planted, primarily in the west. The theory behind high density planting is to use highly precocious cultivars, plant them close together and prune them to keep them within the allotted space. One projection showed trees yielding 4.54 kg/tree at 4 years age and averaging 18 kg/tree at age 8-10, which amounted to 4337 kg/ha/year at 8 years (Meadows and Young 1973).

Unfortunately, the available cultivars were not that precocious; yields were not that high; and pruning methods had not been perfected. Most high density plantings were soon thinned by whole tree removal.

Malstrom and McMeans (1977b) suggest a cross sectional trunk area of 5.7m^2/ha for the southeast which has been obtained within 8 years with high density plantings. Haller and Malstrom (1979) referred to unpublished data of J.D. Hanna that showed declining nut production at 65% shade or higher at noon. One rule of thumb says that crowding occurs when there is more than 50% shade when the sun is directly overhead. If tree canopies touch each other, the orchard floor receives only about 20% sun (Haller and Malstrom 1979), Malstrom and McMeans (1977b) suggested that the diameter of the limbspread would be a better indicator of crowding than trunk cross sectional area and suggested a spacing to occupy 65% of the surface area.

Anderson (1987) compared spacings of 12.2 x 7.6, 12.2 x 15.2 and 15.2 x 15.2 m, but only one year's data was given. The orchard design did not permit a statistical analysis. Yield over all cultivars averaged 11, 10, and 8 kg/tree respectively. 'Cape Fear' yield was 14, 14, and 34 kg/tree, respectively. Increasing spacing increased yield of 'Cape Fear' but not other cultivars. Obviously more years data are needed to overcome the extreme tree to tree variability and alternate bearing. Trunk growth and number of uprooted trees increased with increased spacing. 'Cherokee' was the only cultivar with trunk split with 50% of the 15.2 x 15.2 m spaced trees split and only 18.2% or less of the closer spaced trees split. Broken limbs decreased with increased spacing.

Daniel (1985) reported that trees spaced 9.1 x 9.1 m at Plains, GA were crowded at 12 years. A model that has been created using existing data as a base shows maximum yield for 'Desirable' at 10.7 x 10.7 m and 'Stuart' at 13.7 x 13.7 m (Witt et al. 1989). The model has not been tested and is not likely to be tested. The time required to do such a test would be impractical under the present system of promotion and tenure.

Several studies have given optimum spacings based on trunk cross sectional area. Highest yield/tree for natives was 23.2 trees/ha while highest yield/ha was 34.6 trees/ha or 6.9 m^2 cross sectional trunk area/ha (Hinrichs 1961). Hinrichs concluded that trees should be thinned when trunk cross sectional area exceeds 7.8 m^2. This spacing based on cross-sectional area has become somewhat standard but may or may not apply when trees are planted in equally spaced rows and columns. Malstrom and McMeans (1977b) suggested that 5.7 m^2 of cross-sectional trunk area was optimum for the Albany, GA area while 8.7 m^2 was considered optimum for Texas (Romberg et al. 1959), and 5.7 m^2 was optimum for Louisiana (Smith 1953).

Close spacing makes diseases harder to control. Scab, caused by *Cladosporium caryigenum* was less damaging at a 16 x 18 m than at a 9 x 9 m spacing (Cooper 1983).

Thinning

In 1934 Crane et al. (1934) gave the first data on a thinning study (described earlier under dehorning). Thinning caused the greatest yield/tree, but the increase did not make up for the yield loss from the removed trees after three years. Thinned trees produced the best filled nuts. They reported later (Crane et al. 1935) where trees were thinned, lower limbs drooped, and the top spread out causing the production of new wood and much greater leaf area toward the center of the tree. They concluded that thinning the stand is the only treatment that shows commercial possibilities.

Trees of western U.S. origin appear to bear fruit better on the interior of the tree and thus may be better adapted to pruning. Smith (1938) reported on three years of a pruning and thinning study on 'Burkett' and 'Texas prolific'. He stated that severe pruning such as that reported by Crane et al. (1934) would throw any cultivar out of bearing for several years and suggested that a more moderate pruning system might be practical. In Smith's study, 12-year-old 'Burkett' trees spaced 8.2 x 8.2 m apart were pruned by cutting back the outside branches to reduce the size of the top by 1/5. The branches that were cut back were usually <2.5 cm in diameter and <60-90 cm in length in 1935. This type of pruning was repeated in 1936 and 1937 thus cutting the tree size back to that in 1935. Another block of trees were thinned to 14.7 x 14.7 m apart and compared with the pruned trees. No unpruned and unthinned check trees were left. For 'Texas Prolific', pruned trees were spaced 5.5 x 5.5 m and thinned trees were thinned to a 9.1 x 12.2 m rectangle. Pruned and thinned trees were apparently from different blocks from the beginning for both cultivars. Yield for pruned trees was higher than for thinned trees by 227 to 893 kg/ha depending on year and cultivar. The average yield/tree was greater for thinned trees than for pruned trees, but the number of trees/ha after thinning was insufficient to make up for the difference in yield/ha.

The big difference in favor of pruning in Smith's study (1938) was that 25% of the unpruned 'Burkett' nuts germinated and about 50-60% of the leaves dropped prior to harvest in 1935 while no nuts germinated, and leaves remained healthy on pruned trees. These differences were not apparent on 'Texas Prolific' trees. Smith attributed the sprouting on unpruned trees in 1935 to high rainfall which dissipated better for pruned trees because of the better foliage. Pruned trees of 'Burkett' had a higher percentage kernel and lower nut/kg count than unpruned trees in 1935, but differences were small in other years. Pruned trees also had less downy spot damage and greater nut volume than thinned trees. Thinned trees made more trunk growth than pruned trees. Pruning increased the value of 'Burkett' by $454/ha/yr and Texas prolific by $514/ha/yr for the 3 yrs. One wonders why pruning was not a standard practice in Texas after this study.

Wide spacing looked very good in a spacing-pruning study reported in 1958 (Alben 1958). Old 'Stuart' trees were 12.2 x 18.3 m or had been thinned to 18.3 x 24.4 m. Wider spaced trees had a much lower nuts/kg count and higher % kernel, specific gravity, and vol/nut. Both spacings had the same yield/ha with high irrigation, but with low irrigation, yield/ha was higher for the wider spacing. Net returns/ha was much greater for the wider spacing.

In Texas, 19-year-old trees were thinned to 15 x 15 m or left 10.7 x 10.7 m. Thinned trees made 15.3% more circumference growth, and 17.8% more trunk cross-sectional area growth, and 30% more yield/tree than unthinned trees. Thinning increased nut size and nut wt. but reduced nut specific gravity. Yield of thinned trees would have to be increased by 50% to equal that of unthinned trees on an area basis (Romberg 1959).

Studies in Texas (Managan et al. 1984) showed that yields/tree were highest when trees were thinned, but the yield increase was not enough to compensate for the loss of trees when yield was expressed as yield/ha. Specific leaf wt. was greatest from tree removal and least from topworked trees.

Growth Regulators

The use of growth regulators to control tree size has attracted much interest but has never been accepted as a commercial practice. The use of growth regulators that will shorten internodes or induce more lateral growth is desired. In Texas studies, Alar at 4000 and 5000 ppm was sprayed to the point of runoff in May of 1966 and 1967. Alar increased yield (Storey et al. 1970, Hooks and Storey 1971), bud forcing, precociousness, growth density, green color intensity, shuck disease, % kernel, nuts/kg, and reduced shoot growth (Storey et al. 1970, Hooks and Storey 1971), trunk growth, nut specific gravity, percentage fill, percentage kernel, kernel grade and nut size, and delayed maturity (Storey et al. 1970).

The use of either Atrinal (dikegulac) or Alar did not reduce terminal growth or induce earlier nut production on old dehorned trees (Arnold et al. 1981). The use of dikegulac has induced lateral shoot development (Malstrom and McMeans 1977a, Worley 1980). Foliar applications of dikegulac made three weeks after bud break retarded shoot growth (Malstrom and McMeans 1977a). Paclobutrazol has reduced internode growth and induced lateral buds to break (Worley and Daniel, unpublished), but this material has been discontinued by the manufacturer.

Effects of Pruning and Thinning on Yield

Pruning reduced yield in many studies (Crane et al. 1935, Overcash and Kilby 1973, Storey et al. 1970). In years of high yield selective limb pruning to 12 or 9 m reduced yield (Worley 1987). Hedging reduced yield (Worley 1985). Selective limb pruning reduced yield of 'Elliott' (Worley 1985). In other studies pruning had no effect on yield (Crane 1932a and b, Crane 1933, Hardy 1947). Heading-back had no effect on yield (Hooks and Storey 1971). Selective limb pruning did not affect yield of 'Desirable' or 'Farley' (Worley 1985).

In a few cases pruning increased yield (Anon. 1967). Heading-back increased yield (Kuykendall et al. 1970). Thinning-out of "crows-feet" increased yield (Kuykendall et al. 1970). Thinning increased yield/tree but not yield/ha (Crane et al. 1935, Smith 1938, Romberg et al. 1959, Managan et al. 1984).

Thinning increased yield/ha when moisture was limited, but yields were about the same if sufficient irrigation was provided (Alben 1958).

Effect of Pruning on Flowering, Set and Drop

Pruning increased pistillate flower production (Crane and Dodge 1935) in one report, but in an earlier report it increased the number of pistillate flowers on weak trees but not on strong trees (Crane 1933). Pruning also increased nut

set (Crane 1933, Crane and Dodge 1935) and reduced drop (Crane 1933) but did not affect nuts/cluster (Crane and Dodge 1935).

Effect of Pruning and Thinning on Tree Growth

Pruning has been reported to reduce tree size (Overcash and Kilby 1973) increase trunk growth (Crane 1932a and b) and terminal shoot growth (Anon. 1967, Crane 1932a and b, Crane and Dodge 1935, Worley 1987, Storey et al. 1970); to have no effect on trunk growth (Crane and Dodge 1935, Hardy 1947, Worley 1985); and to decrease trunk growth (Crane et al. 1935, Storey et al. 1970). Pruned trees made less trunk growth than thinned trees (Smith 1938). Pruning usually increases vegetative growth of trees by forcing latent buds (Storey et al. 1970) and by increasing internode length (Hooks and Storey 1971) and leaf size (Anon. 1967). Hedging and selective limb pruning increased terminal shoot growth (Worley 1985).

Pruning increases tree vigor (Worley 1987), green color intensity (Anon. 1967; Storey et al. 1970, Worley 1987) and growth density (Storey et al. 1970).

Thinning increased trunk cross sectional area (Crane et al. 1985, Romberg et al. 1959). Increasing spacing between trees increased trunk growth (Anderson 1978).

Effect of Pruning and Thinning on Nut Quality

One of the most consistent effects of pruning is increasing nut size as shown by increased nut wt. or nut volume (Anon. 1967, Crane 1932a and b, Crane 1933, Crane and Hardy 1934, Crane et al. 1935, Hardy 1947, Smith 1938, Storey et al. 1970, Worley 1985, Worley 1987). Hedge pruning; however, decreased nut volume (Worley 1985).

Sometimes pruning increases other nut quality factors. (Crane 1932a and b, Crane and Hardy 1934). Heading increased % kernel (Storey et al. 1970) and kernel grade (Storey et al. 1970). Selective limb pruning increased kernel grade and percentage kernel in dry years (Worley 1987). Pruning increased percentage kernel over thinning (Smith 1938).

In other studies pruning had little effect on quality. It had no effect on percentage kernel (Overcash and Kilby 1973, Crane and Hardie 1934) and had little effect on specific gravity of 'Pabst' (Crane and Hardie 1934) although it increased specific gravity of other cultivars (Crane and Hardy 1934, Storey et al. 1970).

Pruning increased % fill of some cultivars (Crane 1933, Crane and Hardy 1934, Storey et al. 1970) but had little effect on fill of nuts of 'Pabst' (Crane and Hardie 1934).

Pruning increased value of nuts/ha over thinning (Smith 1938). Thinning increased nut size (Alben 1958, Romberg et al. 1959) and % kernel (Alben 1958). Thinning increased nut specific gravity (Alben 1958) in some instances and decreased it in others (Romberg et al. 1959).

Effect of Pruning and Thinning on Disease Control

Opening of the tree canopy by pruning or thinning usually reduces disease and improves spray coverage. Heading decreased shuck disease (Storey et al. 1970). Pruning reduced preharvest germination of 'Burkett' over thinning (Smith 1938). Pruning reduced downy spot damage over thinning and increased foliage retention of 'Burkett' over thinning (Smith 1938).

Increasing spacing between trees increased uprooting of most cultivars and increased trunk splitting of 'Cherokee' (Anderson 1978).

SUMMARY

Overcrowding of pecan trees must be prevented for them to remain productive. Overcrowding can be prevented by several methods. Wide spacing at planting delays overcrowding but reduces early income from the orchard. Trees should be thinned to give a trunk cross sectional area of between 5.7 and 7.8 m or allow approx 65% of the sunlight to reach the ground at noon. Trees should be thinned before limbs of adjacent trees touch. Pruning may be used to delay overcrowding. "Dehorning" of large trees takes trees out of production for several years and causes excessive vegetative growth and thus should never be used to control tree size. Hedging is also unsatisfactory unless used on a cultivar that bears well on interior wood. Selective limb pruning can be used to mold and hold a tree within size specifications, increase nut size, and improve spray coverage, but the practice is very expensive and has not improved yields. Tip pruning of young trees may be used to increase the number of fruiting terminals of some cultivars. No satisfactory registered growth regulators are currently available for pecan trees.

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PECAN NUTRITION

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Nutritional problems frequently limit orchard productivity. These problems may be apparent such as chlorotic leaves or abnormal growth, on the other hand trees may have no outward appearance of nutritional problems yet production or nut quality is reduced. Diagnostic procedures to identify or avoid nutrition problems have allowed scientists and growers to improve fertility programs for pecan.

LEAF AND SOIL ANALYSIS

Soil tests are beneficial to determine the soil fertility level prior to planting, to monitor soil pH of established orchards, and as a diagnostic tool when an unusual problem exists. However, routine soil testing to guide orchard fertility programs is generally unsatisfactory. This is because soil test values correlate poorly with elemental absorption (Wear and Cope 1976). Minimum acceptable soil concentrations for selected elements are listed in Table 1.

Leaf analysis is the most satisfactory method to access the nutritional status of mature orchards. The standard index tissue for pecan is the middle pair of leaflets from the middle leaf on current season's growth. Samples are normally collected during July, but this may vary among locations depending on growing season and the time period for which standard composition values are established. Recommended leaf elemental concentration ranges for some states are listed in Table 2.

SOIL pH

Soil pH affects the availability of nutrients as well as root growth and tree longevity. Sparks (1976b) reported that tree growth was reduced as soil pH decreased from 5.3 to 4.5. Pecan root growth was greatest when soil pH was 6.5 to 7.5 (Bailey and Woodroof 1932, Johnson and Hagler 1955). White (1982) found increased taproot and feeder root growth in pecan when lime was added to the subsoil rather than to the topsoil. Although root growth is optimum up to pH 7.5, availability of some micronutrients is severely restricted above pH 7.0; therefore, the optimum soil pH for pecan trees is 6.5 to 7.0.

NITROGEN

The lowest recommended N concentration sufficiency range is 2.3-3% in Oklahoma and the highest is 2.7-2.9% in Georgia and Alabama (Table 2). The most common minimum sufficiency concentration is 2.5%. Differences in the minimum sufficiency concentration among the states reflect differences in growing seasons (rainfall, light intensity, temperature, humidity), tree type (native vs. cultivar), dominant cultural practices (irrigated vs. non-irrigated, orchard floor management, intensity of pest control), soil types, and grower and scientist management objectives. Although the minimum sufficiency concentrations for N are different among states, there is a great deal of overlap in the sufficiency ranges among states.

Nitrogen application can cause a reduction in the concentration of other elements in the tree. This occurs when tree growth is stimulated by N application, but there is an inadequate supply of another element to meet the needs of increased growth. In one study, N rate was negatively related to leaf K and P concentration (Smith et al. 1985). High N application rates can cause marginal chlorosis or necrosis of leaves called "nitrogen scorch" (Sparks 1976a). Scorch symptoms, which develop during June or July, occur more frequently on young vigorous trees than on mature trees, and are more common on 'Desirable' than other cultivars. These symptoms appear to be common in Georgia (Sparks, Wood, Worley, personal communications), rare in Louisiana (O'Barr, personal communications), and have not been reported in Oklahoma, Texas, Arizona or New Mexico (Herrera, Kilby, Smith, Storey, Taylor, personal communications). Sparks (1976a) reported that leaf scorch appears to be caused by a shortage of K induced by excess N fertilization, but Worley (1990) found that leaf N and K concentration were not closely related to leaf scorch.

Legumes were an extensively utilized N source in pecan orchards in the 1950's and earlier; however, inexpensive commercial N sources caused a decline in their use. Interest in legumes as a cover crop has been renewed by rising N fertilizer prices,

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environmental issues, and their potential use in integrated pest management programs (Wood et al. 1983, Tedders 1986). The N fixation potential of legumes is influenced by the species (Table 3), type of *Rhizobium* - inoculate, environmental conditions, and availability of soil N (White et al. 1981). Studies on pecan indicate that some legumes can supply about 100 kg N/ha to the pecan (Smith et al. 1960, White et al. 1981, Wood et al. 1983). Additional research is needed to identify legume species and cultivars that will meet the requirements of an orchard management program.

PHOSPHORUS

Total soil P content is variable in the U.S., but P is generally lower in humid regions of the southwest than in the central and western states (Tisdale and Nelson 1966). Fertilized soils can be quite high in P since little of this element is lost in percolating water and crop removal is small compared to N and K.

Phosphorus deficiency symptoms include pale green foliage that may develop interveinal chlorosis. Necrotic tissue near the leaf margin may develop when the shortage is severe, followed by defoliation (Sparks 1988). These symptoms are more pronounced on shoots with fruit than on shoots without fruit (Sparks 1977).

Pecan fruit contain a substantial amount of P that is transported into the fruit in greatest quantities during kernel development (Krezdorn 1955, Diver and Smith 1984). Most of the P in the fruit is located in the kernel, and the shuck P content is higher than the shell (Sparks 1975, Diver and Smith 1984). Krezdorn (1955) reported that the leaf P concentration of 'Success' was lower in trees with heavy crops than light crops during the latter part of the growing season. Sparks (1977) found that leaves on shoots with fruit had less N, P, K and Zn than leaves on shoots without fruit, and that leaf scorch (necrotic tissue on the leaf margins) and defoliation were more severe when fruit were present on the shoot. Later research by Sparks (1988) implicated low leaf P as the major cause of leaf scorch and defoliation. The greater severity of P deficiency on shoots with fruit appears to result from large quantities of P transported to the fruit during kernel development (Diver and Smith 1984).

Leaf P concentrations have also been related to cold damage. Smith and Cotten (1985) found that cold damage of 32-year-old 'Western' trees decreased as leaf N increased from 1.9% to 2.5% and leaf P increased from 0.11% to 0.17%. Trees also had more cold damage as yield per tree increased.

Response of pecan to applied P has been inconsistent. The chief reasons for the variable responses are lack of P movement into the root zone from surface applications thus limiting P absorption by the tree (Worley 1974, Worley et al. 1974, Worley 1977), the native P content of the soil (Worley et al. 1974) and the nutrient status of the tree (Alben and Hammar 1939, Worley et al. 1974). There are no reports of improved yield, but two studies have found P applications improved kernel yield (Hunter 1951, Sparks, 1988).

Minimum leaf P concentration recommended for pecan range from .1% in Arizona to .18% in Georgia (Table 2). Most states use .12% as the minimum acceptable leaf P concentration. Sparks (1986a, 1988), based on greenhouse and field tests, suggested the minimum sufficiency level of P for pecan is too low. He found that maximum vegetative growth of greenhouse-grown pecan seedlings occurred when leaf P concentrations were 0.19 to 0.22%. Field studies with adult trees showed that greatest nut growth and minimum leaf scorch and defoliation occurred when leaf P was greater than 0.14% and 0.16%, respectively.

POTASSIUM

Typically, soils of the southeastern and southern coastal plains of the United States are low in K because they are formed from marine sediments that are highly leached (Tisdale and Nelson 1966). Soils of the mid-south are usually low in K although they are from high K bearing minerals. Because of their age and the climate, leaching has decreased their K content. Soils from the mid- and far-western states are typically high in K, except where high rainfall has leached K.

Potassium comprises about 58% of the total elemental content of the fruit (Sparks 1975). The shuck contains the majority (86%) of the K (Diver and Smith 1984), which is returned to the soil when the shucks abscise. Potassium removal by nut harvest is about 10 g/kg of nuts.

The most rapid transport of K into the fruit is during the final 30 days before the fruit ripen (Diver and Smith 1984). This high demand for K by the fruit, decreases leaf K concentrations (Krezdorn 1955, Sparks 1977, Diver and Smith 1984), and can induce K shortage causing leaf scorch or defoliation (Sparks 1976a). Hunter and Hammar (1948, 1956) reported that reduced kernel and oil content may be attributed to K shortage.

Early symptoms of K shortage are irregular interveinal chlorosis which appears first on older leaves and leaflets. As the shortage becomes more severe, the chlorotic symptoms progress to the younger leaves. Severe K shortage causes a marginal scorch which can spread over most of the leaf margin, eventually causing leaf death (Sparks 1976a). These symptoms frequently develop on young 'Desirable' trees, particularly if N fertilization was high (O'Barr, Sparks, Wood, Worley, personal communications). 'Desirable's' greater susceptibility to leaf scorch, and responsiveness to K fertilization (Worley et al. 1974) suggests that 'Desirable' may have a greater K requirement than most other cultivars.

Potassium shortages occur frequently in pecan, and when severe may require several years to correct (Smith et al. 1985). Potassium applications to the soil surface of a fine-textured soil required 5 years before leaf K concentrations of mature 'Western' trees were consistently increased (Smith et al. 1985), but only 1 year's application was required to increase leaf K concentrations on young 'Desirable' trees growing in a sandy soil (Worley et al. 1974). Foliar applications of K_2SO_4 or KNO_3 either applied with or without NH_4NO_3 and/or urea were not effective in supplying K to adult pecan trees (Smith et al. 1987).

CALCIUM

Calcium shortages are normally associated with low pH soils. Frequently, either excesses of some micronutrients or shortages of certain macronutrients will occur because of low soil pH before Ca is in short supply. Normally, Ca shortages are corrected by the application of lime which also increases the soil pH. In those instances when the soil pH is within an acceptable range but Ca is low, calcium sulfate can be used without affecting the soil pH.

MAGNESIUM

Magnesium shortages have been identified in the acid soils of Georgia and Florida (Sharpe et al. 1950; Worley, 1975). These shortages of Mg were more severe when orchards had been heavily fertilized with K fertilizer, since K reduces Mg absorption. Worley (1975) found dolomitic limestone was more effective than foliar Mg sprays in correcting these shortages. Similarly, Sparks (1986a) reported that foliar Mg applications were not as effective in increasing leaf Mg concentration and growth of pecan seedlings as root supplied Mg.

SULFUR

Sulfur deficiencies are rare among the nut crops. This is because S is often included in other fertilizers applied to the crop such as P, $(NH_4)_2SO_4$, and $ZnSO_4$. In addition, S is added to the soil from atmospheric pollution. Sulfur deficiency symptoms are similar to those of N deficiency. Leaves have a pale green color and trees lack vigor.

Minimum recommended sufficiency concentrations for S range from .25% in Georgia, to .1% in Arizona and New Mexico. There has been little research to support these minimum S concentrations, which contributes to the wide range in recommended concentrations among locations. Sparks (personal communication) reported that leaf S concentrations below .2% caused a decline in tree growth, and deficiency symptoms were apparent at .1% S.

ZINC

Typical Zn deficiency symptoms include small leaves with wavy margins and interveinal chlorosis. In severe cases, internodes are shortened and shoot tips die, causing a bunchy growth habit. Yields are frequently reduced by Zn shortages prior to visual symptoms.

Zinc shortages occur in all areas where pecans are grown. Pecan trees in the southeastern U.S. have responded to soil applied Zn (Worley et al. 1972, Payne and Sparks 1982) unlike trees in the western U.S. (Smith et al. 1980). The major difference is that soils in the western region have a higher soil pH with greater Ca and Mg concentrations which renders the Zn unavailable soon after application. In the southeastern U.S., soil application of 2.2 to 4.4 kg of 36% zinc sulfate per tree depending on tree size and severity of the Zn shortage has corrected Zn problems (Sparks 1976c). In the western U.S., Zn is applied using 3 to 6 foliar sprays. Smith and Storey (1979) reported that $ZnNO_3$ was more efficient than $ZnSO_4$ in increasing leaf Zn concentration, especially if tank mixed with a urea/ammonium nitrate solution.

IRON

Iron sufficiency ranges are similar for all states that were surveyed (Table 2). Most Fe shortages that have been observed were induced by cool, wet spring weather but as temperatures increased, deficiency symptoms were alleviated.

BORON

Boron excess is a more common problem than B shortage. Symptoms typical of excess B include marginal leaf scorch which extends toward the midrib. Leaves may fall prematurely and if the excess is severe, shoot dieback may occur. Excess B is usually associated with high B levels in the irrigation water (Kilby, personal communications). In these cases, the only correction method is an irrigation source with acceptable B concentrations.

Boron sufficiency ranges vary among states (Table 2). New Mexico and Arizona sufficiency ranges are greater than those from other states. These high ranges probably reflect greater B in soils and irrigation water, and pecan tolerance to B rather than the concentration needed for maximum growth and production.

COPPER

Copper sufficiency ranges are similar among states (Table 2). Little work has been conducted in the field to confirm these sufficiency ranges, but observation by researchers indicate that these concentrations are adequate. Occasional leaf Cu concentrations below these sufficiency ranges have been observed, and $CuSO_4$ soil applications have increased leaf Cu concentrations into the sufficiency range (Storey, personal communications).

MANGANESE

No cases of Mn shortage have been documented on pecan. Greenhouse studies have indicated pecan trees require at least 50 $\mu g/g$ leaf Mn for normal growth. In the field, pecan trees with up to 2500 $\mu g/g$ leaf Mn have been identified with no apparent damage (O'Barr, personal communications; Smith, unpublished).

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Table 1. Minimum soil elemental concentrations for pecan.

Element	Concentration ($\mu g/g$ soil)
P	10
K	100
Mg	50
S	25
Mn	1
Cu	0.16
B	0.40

Source: J.B. Storey, Texas A&M University

Table 2. Leaf elemental concentration sufficiency ranges for pecan.

	Dry Weight (%)						Dry Weight (μg/g)					
State	N	P	K	Ca	Mg	S	Zn	Fe	Mn	B	Cu	Source
GA	2.7-2.9	>.18	1.3-1.5	1.3-1.5	.35-.6	>.25	>50	>50	>100	35-50	>7	Sparks
GA	2.7-2.9	>.12	>.75	1.3-1.5	.35-.6	>.25	>50	>50	>100	35-50	>7	Worley
AL	2.7-2.9	.12-.3	.75-.95	.7-1.5	.4-.6	NA	50-100	50-330	100-800	20-45	10-30	Goff
LA	2.5-3.0	.12-.19	.75-1.25	.7-2.0	.3-.6	.18-.25	51-150	50-300	75-2500	20-45	6-20	O'Barr
OK	2.3-3.0	>.12	>.75	>.7	>.3	NA	>60	>50	>100	NA	NA	Smith
TX	2.5-4.0	.12-.3	.75-1.25	.7-3.0	.3-.6	NA	80-500	50-300	40-300	20-45	10-30	Storey
NM	2.5-3.0	.12-.19	.9-1.2	.9-1.8	.3-.6	.1-.15	50-100	50-250	100-600	50-200	8-30	Herrera
AZ	2.5-3.5	.1-.18	1.0-2.0	1.5-3.0	.4-.5	.1-.15	>60	>50	>80	100-300	NA	Kilby

Table 3. Seasonal total dinotrogen fixation by legumes measured by difference or isotype dilution methods.

Species	N^2 Fixation (kg/ha N/growing season)	Location	Measurement method	Reference
Birdsfoot Trefoil	49-112	Minnesota	Isotope dilution	Heichel et al. 1985
Crimson Clover	64	New Jersey	Difference	Sprague 1936
Hairy Vetch	111	New Jersey	Difference	Sprague 1936
Ladino Clover	165-188	Maryland	Difference	Wagner 1958
Red Clover	68-113	Minnesota	Isotype dilution	Heicher et al. 1985
Subterranean Clover	58-183	California	Isotope dilution	Phillips and Bennett 1978
Sweetclover	4	New Jersey	Difference	Sprague 1936
White Clover	128	Kentucky	Difference	Karraker et al. 1950

PECAN GROWING AREAS IN THE WESTERN REGION: CURRENT SITUATION AND FUTURE OUTLOOK

Esteban A. Herrera[1], Sammy Helmers[2], G. Steven Sibbett[3] and Mike Kilby[4]

ABSTRACT

Pecan acreage in the western region covers about 57,000 acres. It involves west Texas, southern New Mexico, southern Arizona and southern California. The first commercial pecan orchard in the region was planted in Las Cruces in 1914. 'Western Schley' is the main cultivar grown with 'Wichita' being second (it is planted mainly as a pollenizer). Some orchards in Arizona and California use 'Wichita' as the main cultivar and 'Western Schley' as a pollenizer. Although, no significant plantings are likely to occur in the near future, these cultivars will continue to be predominant. Currently, aphids are the main insect problem but pecan nut casebearer will eventually move to the western region from El Paso, TX area. Use of insecticides will tend to diminish and use of beneficials will increase. Tree crowding is becoming a major problem in orchards planted 30 ft. x 30 ft. spacing. Tree thinning and tree transplanting will expand.

GENERAL DESCRIPTION

The oldest known planting in the western region is located at the Fabian Garcia Agricultural Science Center of New Mexico State University, in Las Cruces, NM. Four acres were planted there in 1914, many of which are still in production on this site. The first large-scale commercial planting of pecans in New Mexico, 30 acres, was made by the late Deanne F. Stahman in 1934 south of Las Cruces. It was not until the early 1960's that a tremendous interest in planting pecan orchards developed; production from earlier plantings showed, for the first time, that a pecan orchard could be economically justified.

Currently, pecan orchards in the western region spread over 57,000 acres including far west Texas, southern New Mexico, southern Arizona and southern California. (Figure 1). The combined production of all these areas in 1989 amounted to 58 million pounds (Table 1) (National Agricultural Statistics Service, USDA 1990).

'Western Schley' is the predominant cultivar grown in the West with 'Wichita' second and planted mainly as a pollinator. Some orchards in Arizona and California use 'Wichita' as the main cultivar and 'Western Schley' as the pollenizer. In New Mexico about twenty percent of the orchards and some old orchards in Arizona use 'Ideal' (Bradley) as a pollinator.

Flood irrigation is used in areas where water is supplied from reservoirs Whenever water wells are used, furrow irrigation and low volume irrigation (drip, trickle or sprinkler-type) is also used. Usually, most orchards change to flood or furrow irrigation once they reach full production (12-14 years). Lately, more and more orchards are retaining low volume irrigation systems after orchards reach full production.

The recommended plant spacing in the western region is 30 ft. x 30 ft. Tree crowding eventually occurs and some growers thin out trees to prevent shading and production loss. Unfortunately, most growers do not do this soon enough and a considerable number of bearing limbs die in lower parts of trees. Pecan production usually increase with good tree thinning practices.

Pecan trees in the western region do not suffer disease problems as is encountered in the eastern region. In the early days of the western region pecan industry *Phymatotrichum* root rot (also known as Texas root rot) affected young trees. However, it is not much of a problem today because few trees are planted. Insect problems have until recently, included only the aphid complex (blackmargined, yellow and black aphids). Insecticides used to control aphids are highly successful but aphid resistance develops with continual use. Currently, it is recommended that different insecticides be used every year so as to prevent resistance build-up. With the exception of the southeastern counties in the state of New Mexico, the western region had been free of the

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pecan nut casebearer (PNC). This insect was first spotted in El Paso, TX in 1987. In 1989, it was reported in the upper El Paso Valley but is not yet in New Mexico.

Pecan harvesting usually starts in the second half of November. Most growers in the area wait for the first hard freeze to bring pecan moisture down and to cause shucks to open.

CURRENT ACREAGE, BY AREAS

Arizona

There are 20,500 acres of pecan trees in Arizona, mainly in Cochise, Pima, Pinal, Maricopa, Mohave, La Paz and Yuma counties. Most orchards are over 20 years old. Over the last five years this acreage has averaged 20 million pounds per year.

'Western Schley' is the main cultivar and is well adapted to the state's areas of climate, soil and elevation. 'Wichita', used mainly as pollenizer is the most productive cultivar; but, high soil pH (zinc deficiency problems) and high soluble salts in the soil reduce productivity. At low elevations (below 3500 ft.), kernels tends to be darker with hotter temperatures. 'Wichita' can only be planted in the correct environment, 'Western Schley' is better adapted to Arizona's soils and climate. 'Ideal' has also been used as a pollenizer. It is well adapted to growing areas in Arizona. Unfortunately, it is not well accepted in the market place due to small nut size. A few growers have tried 'Barton' as a pollenizer but did not like the alternate bearing behavior.

In general, most other pecan cultivars, including newly-released USDA cultivars, are not recommended for Arizona. These varieties have nut quality problems and are susceptible to zinc deficiency.

California

California is the newest area in the western region. It has more varied climate than the other states in the western region and may possibly be able to profitably grow varieties that the other western states are unable to grow. Currently pecan acreage in California is about 3,500 acres, mainly in southern San Joaquin Valley; encompassing Tulare, Kings, Fresno, Kern, Madera and Merced counties. Some orchards are also located in the more northern counties of Butte and Colusa. Tree age varies from one to fifteen-years-old, most pecan acreage is around ten-years-old. Annual production from this developing acreage is currently listed around two to three million pounds.

In the southern San Joaquin Valley, 'Wichita' is the recommended cultivar. Its major problem is limb breakage. California's early harvest causes shell cracking due to rapid drying unless careful processing is used. 'Western Schley' is the preferred pollenizer with 'Cheyenne' being the second choice. 'Cheyenne' is difficult to manage due to limb breakage, susceptibility to zinc deficiency and susceptibility to aphid infestation. 'Cheyenne' also has limited value because of small nut size. 'Western Schley' is an excellent cultivar in California but does not begin bearing as soon as 'Wichita'. Thus growers prefer 'Wichita' for the main pecan cultivar.
In the northern area of California cultivars with shorter growing seasons are recommended. 'Pawnee' has a short growing season and therefore adapts well. Performance of this cultivar has not been well established in that area. Other cultivars are being studied because of production problems noted in other areas, but length of growing season must be considered first in cultivar recommendations for the northern areas.

New Mexico and Far West Texas

Apart from a high water table in some acreage located in the lower El Paso Valley; these two areas have similar soils and climate. The same cultivars are grown and similar orchard problems exist.

All 21,000 acres of pecans planted in New Mexico, are grown in the southern area; 65% of which are located in Dona Ana County, the rest in adjacent counties of Luna, Sierra, Otero, Lea, Eddy and Chaves. Far west Texas, defined as the area south of Midland-Odessa and west of a line from Big Springs to Del Rio, has approximately 12,000 acres with 50% of that located in El Paso County. The reminder occurs in Pecos and Culberson counties and the Permian Basin area. The combined annual production for far west Texas and southern New Mexico is about 40 million pounds.

REGIONAL CULTIVARS

'Western Schley' is the main cultivar planted in the western region, 'Wichita' trees are used as pollenizers. In some old orchards, growers planted 'Ideal' ('Bradley') trees for pollination; later 'Wichita' trees were preferred as pollinator trees because of better market prices based on high percent kernel and color. Most orchards have planted around 10% of pollinator trees.

'Western Schley'. 'Western Schley' is the most popular cultivar because it is a consistent producer, self-pollinated, it is more drought tolerant than any other cultivar, tolerant to zinc deficiency, produces a high kernel percent, shells easy, has good kernel color and has demanded good prices. 'Western Schley' is the most versatile cultivar available, adapting to a wide range of environmental conditions.

'Wichita'. 'Wichita' is 'Western Schley's' best pollinator, pollen shed overlaps well with 'Western Schley's' stigma receptivity, while the reverse is also true, for 'Western Schley' and 'Wichita'. Despite 'Wichita's' problems with limb breakage, zinc deficiency, freeze susceptibility and drought sensitivity, no other pollinator tree can produce the quality kernels of 'Wichita'. 'Wichita' nuts consistently yield around 60% kernel every year, they are large and well accepted by consumers; in spite of the fact that kernel tends to be off color under hot weather conditions.

'Ideal'. 'Ideal' pecans have good kernel color, they have good kernel percent and shell easy, trees produce good crops every year. However, nuts are small and are not well accepted in the market, trees are highly susceptible to yellow aphids.

'Cheyenne'. 'Cheyenne' is a cultivar with good kernel color and high kernel percent (58-59%). The nuts shell easy, producing mostly halves. It is a consistent bearer, however nuts are small. The trees need special training because limbs are weak and brittle. 'Wichita' is the preferred pollenizer for this cultivar. In most pecan orchards in California, where 'Wichita' cultivar is the main variety, 'Western' and 'Cheyenne' trees are used as pollinators, 'Western Schley' being the first choice.

'Tejas'. 'Tejas' is a cultivar often mentioned as a possible pollinator tree for 'Western Schley'. It produces a pecan with about 56% kernel, of good color that shells easy in good years. However, because of its small nut size it is limited to the "in-shell" trade. It is a vigorous tree, is also an alternate bearer regardless of orchard management practices. In some years, 'Tejas' is not pollinated by 'Western'. It could be a good pollinator tree for home orchards, because it is not susceptible to zinc deficiency and water stress as 'Wichita' trees.

Other Varieties

'Stuart'. 'Stuart the most planted cultivar in the country (Thompson 1990), is not popular in the western region because it is not precocious and nuts have low kernel percent (below 50%). Their low quality pecans cannot compete with currently used cultivars.

'Desirable'. 'Desirable' the third most common cultivar in the States, just behind 'Western Schley' (Thompson 1990), is a cultivar that does well in the Permian Basin area. Zinc-deficiency is not a problem and it does well even with ordinary management. It produces low crops, but it is consistent. However, the nuts have 54% kernel or less and it is only sold to the "in-shell market".

'Barton'. 'Barton' a popular variety in early plantings in this region but is no longer planted in the West. It produces heavy crops of poor quality nuts in one year and almost no crop the next.

USDA CULTIVARS

Most new cultivars released by USDA show zinc deficiency symptoms in the western region. These cultivars will not be widely planted until growers observe them under commercial conditions, especially at full production.

Of all recently released cultivars, 'Pawnee' may have greatest potential. Nuts of this cultivar have 58-59% kernel with a nice golden color, nuts are large and shell easy. 'Pawnee' is a protandrous cultivar and could be pollinated by 'Wichita'. It will be ready for harvest in late September, which can be an advantage in years when prices are high early in the market season. They will have to be harvested at higher moisture levels and be artificially dried to take full advantage of an early market.

FUTURE OUTLOOK

It appears that pecan acreage in the western region will not increase significantly in the near future. In fact, few orchards have been planted in New Mexico and Arizona in the last five years. Most new plantings have taken place in Far West Texas (Midland and Pecos counties) and in California. Any significant pecan planting that may occur in the future will probably take place in California. Some reduction in pecan acreage has occurred in Arizona (around 3000 acres) at low elevations; due to poor nut quality, salinity problems and water cost.

'Western Schley' will continue to be the main cultivar and 'Wichita' the pollenizer. It is probable that new growers would prefer to plant 'Wichita' trees in one block for better management. In northern California, some areas may be suitable for planting short season cultivars such as 'Pawnee'.

Orchard thinning (with some tree transplanting to enlarge acreage) will increase as tree crowding continues. Pecan nut casebearer will eventually reach all pecan growing areas in the West and growers will need to learn techniques to deal with this pest. Growers will tend to reduce the use of insecticides, predators and orchard floor management will increase in popularity. Some orchards in the region are already producing pecans without applying insecticides.

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Table 1. Acreage and pecan production in the western pecan growing region, 1989.

State	Acreage	Production (Million lbs.)
Arizona	20,500[1]	15.0[1]
California	3,500	2.0
New Mexico	21,000	29.0
Texas (Far West)	12,000[1]	12.0[1]
Total	57,000	58.0

[1] Estimated

National Agricultural Statistics Service, USDA

CULTIVARS FOR THE EAST

William D. Goff[1]

ABSTRACT

Leading pecan (*Carya illinoensis* Wang. K. Koch) cultivars in the eastern U. S., in decreasing order of existing acreage in 1990, include Stuart, Desirable, Schley, Cape Fear, Moneymaker, Cheyenne, Success, Wichita, Mohawk and Moore. Cultivars recommended by pecan researchers and extension specialists for planting in the most eastern states, in decreasing order of number of states in which they are recommended, are Desirable, (recommended in 9 of fourteen states considered), Cape Fear (9), Stuart (9), Kiowa (7), Peruque (6), Choctaw (5), Colby (5), Cheyenne (5), Giles (5), Mohawk (5), Pawnee (5), and Forkert (5). Cultivars increasing from 1983 to 1990 in number of states in which they are recommended include Pawnee, Gloria Grande, Moreland, Shawnee, and Success; while those declining by more than one in number of states in which they are recommended are Cheyenne and Shoshoni.

Thompson (1990) has recently surveyed pecan researchers and extension specialists to estimate acreage planted to various cultivars, and to determine which cultivars are currently recommended in the various states. In this paper, I will emphasize the humid areas of the eastern U.S. where appreciable commercial pecan production is found, and will draw from Thompson's survey and discuss cultivars found and recommended in these areas. The areas I will concentrate on include eastern Texas, Oklahoma, Arkansas, Mississippi, Louisiana, Alabama, Florida, Georgia, South Carolina, and North Carolina. In Kansas, Missouri, Kentucky, and Tennessee, and to a limited extent in a few other eastern states, pecans are grown, but commercial acreage (Table 1) is small relative to more southern areas, and adaptability to the cooler climate becomes the dominant character in cultivar selection.

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Relative production of pecans in the major pecan producing states for the 10-year period from 1977-1986 is illustrated in Figure 1.

In terms of acreage planted (Table 1), the ten leading cultivars in the East (east Texas excluded because of unavailability of cultivar and acreage breakdown within Texas) are Stuart, Desirable, Schley, Cape Fear, Moneymaker, Cheyenne, Success, Wichita, Mohawk, and Moore. Some of these cultivars are no longer recommended for planting in most of the states (Table 2), but existing older plantings keep acreage figures high. Schley, Moneymaker, Success, and Moore are noteworthy examples of cultivars which have substantial acreage existing, but are not widely recommended for planting now.

Cultivars currently recommended for planting in the East are listed by state in Table 2. Those making recommendations commonly divide their state's list into cultivars recommended for home plantings, and those recommended for commercial plantings. The ten cultivars recommended in the most eastern states for home planting are Stuart (9 of 14 states), Elliott (7), Cape Fear (6), Desirable (6), Peruque (6), Choctaw (5), Colby (5), Gloria Grande (5), and Major (5). Of these, Peruque, Colby, and Major are suggested only in the northern part of the range. In Alabama, we assume that homeowners will be unable to spray pecan trees because of restrictions and prohibitive costs of spray equipment for large trees. Because of this inability to spray, tolerance to pests, especially scab [*Cladosporium caryigenum* Ell. and Lang. (Gottwald)], is the overriding criterion we use in selecting cultivars for our home recommendations.

For commercial plantings in the East, the 12 cultivars recommended by the most of the 14 states we are considering are Stuart (9), Cape Fear (9), Desirable (9), Kiowa (7), Peruque (6), Choctaw (5), Colby (5), Cheyenne (5), Giles (5), Mohawk (5), Pawnee (5), and Forkert (5). Peruque, Giles, and Colby are recommended only in the more northern areas.

A comparison of Thompson's 1990 survey (Thompson, 1990) with a similar survey done in 1983 (Thompson, 1984) reveals which cultivars are gaining or losing popularity. Considering all states surveyed by Thompson, the following cultivars increased most from 1983 to 1990 in number of states recommending them. Pawnee, released in 1984, of course was not recommended by any state in 1983, but was recommended by five states (three were trial only) in 1990. This gain

of five states far exceeds increases by any other cultivar. A gain of two states was made by Moreland (two recommending in 1983, four in 1990), Gloria Grande (four in 1983, six in 1990, with two recommending for home plantings only), Shawnee (one in 1983, three in 1990, with two trial only), and Success (0 in 1983, 2 in 1990). No other cultivar had more than a one state increase in number of states in which it was recommended in 1990 compared with 1983.

The cultivar which lost the most states, when 1983 recommendations are compared with 1990 recommendations, was Cheyenne. This cultivar was recommended in twelve states in 1983, but in only eight in 1990, a loss of four states. Only one other cultivar, Shoshoni, lost more than one state. Shoshoni was recommended in five states in 1983, and dropped to three states in 1990. Twelve other cultivars were recommended in one fewer state in 1990 than in 1983. These are Apache, Chickasaw, Choctaw, Cowley, Desirable, Farley, Hayes, Jack Ballard, Kiowa, Oakla, San Saba Improved, and Sumner.

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Table 1. Estimated acreage in eastern states planted to various pecan cultivars. (Adapted from Thompson, 1990).

Rank[z]	Cultivar	AL	AR	FL	GA	KS	KY	LA	MS	MO	NC	OK	SC	TN	TX	Total	Total excl. Texas
									State								
1	Stuart	27500	4500	41357	7800	12500	2400	4800	5000	2	12000	117879	105879				
2	Desirable	4400		3000	27982		1200	3000	200	50	100	19000	58932	39932			
3	Schley	5500	17863		240	500		240	500			300	2500		2000	28903	26903
4	Cape Fear	4400			5140			187			1000		100		1000	11827	10827
5	Moneymaker	3850	750	4913				500				100			500	10613	10113
6	Cheyenne	2200			7077			14				150			16000	25441	9441
7	Success	3850			1739				800	500			725	100	6000	13714	7714
8	Wichita				4884			20				550			36000	41454	5454
9	Mohawk				842	100							2500	5	4000	7447	3447
10	Moore			1200	1758			25							4000	6983	2983
11	Chickasaw				2679											2679	2679
12	Mahan							100	1250			600	100	8	5000	7058	2058
13	Maramec					50		2				2000				2052	2052
14	Sumner				1767			50								1817	1817
15	Frotscher				1647								100			1747	1747
16	Elliott				1686											1686	1686
17	Pabst				1450			100						100		1650	1650
18	Teche			1520												1520	1520
19	Van Deman	1306						10				50			800	2166	1366
20	Mobile				883								100			983	983
21	Delmas				894										1000	1894	894
22	Peruque					150				250		150				550	550
23	Kiowa				368			50							4000	4418	418
24	Giles					250				150				5		405	405
25	Western Schley											400			51000	51400	400
26	GraKing											325			500	825	325
27	Shoshoni				107	100		116							700	1023	323
28	Choctaw											300			6000	6300	300
29	Burkett											300			1000	1300	300
30	Gloria Grande				113								100			213	213
31	Pawnee				102	50									500	652	152
32	Squirrel's Del.											150			300	450	150
33	Hirschi					50				100						150	150
34	San Saba Impr.											100			7000	7100	100
35	Sioux											75			4000	4075	75
36	Barton											75			1500	1575	75
37	Caddo							25							1500	1525	25
38	Cherokee														2000	2000	0
39	Tejas														2000	2000	0
40	Ideal														1500	1500	0
	Unknown/other	3300	4500	5550	21923	450	75	1071	7250		400	3000	1700	110	9200	58529	49329
	TOTAL	55000	4500	15000	150000	1200	75	12310	25000	500	4000	16700	10000	150	200000	493935	294435

[z]Rank is according to totals for all states listed excluding Texas. Acreage breakdown of cultivars in eastern Texas unavailable.

Table 2. Pecan cultivars recommended for planting in eastern states. (Adapted from Thompson, 1990).

	State															
Cultivar	AL	AR	FL	GA	KS	KY	LA	MS	MO	NC	OK	SC	TN	east TX	no. states rec. for home plantings	no. states rec. for comm. plantings
Stuart	C	CH	CH	CH				CH		CH	CH	CH	CH		8	9
Cape Fear	C	CH	C	C			CH	CH		CH		CH	CH		6	9
Desirable	CH	CH	C			C	CH		CH		CH		CH		6	9
Kiowa	C		C				C	C			CH	CH		CH	3	7
Peruque		CH			CH	CH			C		CH		CH		5	6
Choctaw		CH						CH			CH	CH*		CH	5	5
Colby		CH			CH	CH					CH		CH		5	5
Cheyenne		CH	C								CH	CH		CH	4	5
Giles		CH			CH				C		CH		CH		4	5
Mohawk	CH							C			CH	CH	CH		4	5
Pawnee	C*	CH			CH						CH			C*H*	4	5
Forkert	C	CH						C*	CH			CH			3	5
Gloria Grande	CH	CH	C	H			H					CH			5	4
Major		CH			H	CH			CH				CH		5	4
Moreland	CH	CH	CH				C								3	4
Posey					CH	CH			C				CH		3	4
Sumner	CH			C	C		CH								2	4
Elliott	H	CH	CH	H			H	H				CH			7	3
Melrose	C*H	C*H*					CH	H							4	3
Greenriver		CH					CH						CH		3	3
Shoshoni		CH											CH	CH	3	3
Caddo		CH					C							CH	2	3
Hirschi					CH				C		CH				2	3
Shawnee	C*H*						C*			CH					2	3
Candy		CH					CH	H							3	2
Owens	H	CH						CH							3	2
Chickasaw		CH										CH*			2	2
Success		CH										CH			2	2
Tejas		CH									CH				2	2
Wichita	CH										CH				2	2
Jackson	H	CH					H	H							4	1
Burkett		CH													1	1
Cherokee		CH													1	1
Dooley					CH										1	1
Gormley											CH				1	1
GraKing											CH				1	1
Hodge						CH									1	1
Jubilee	C*H*														1	1
Kansas					CH										1	1
Lewis		CH													1	1
Love					CH										1	1
Mahan		CH													1	1
Mahan-Stuart		CH													1	1
Maramec											CH				1	1
Moneymaker		CH													1	1
Moore		CH													1	1
Mount											CH				1	1
Schley		CH													1	1
Seminole		CH													1	1
Sioux											CH				1	1
Squirrel's Delight											CH				1	1
Starking Hardy Gi.		CH													1	1
Western Schley											CH				1	1
Mississippi							C*								0	1
Oconee							C*								0	1
Surprize	C*														0	1
Woodard	C*														0	1
Curtis			H	H			H								3	0
Davis	H							H							2	0
Barton								H							1	0
Canton					H										1	0
Total	18	36	10	7	11	6	16	14	5	3	20	13	9	7		

C - Commercial plantings. H - Home plantings. *Trial plantings only.

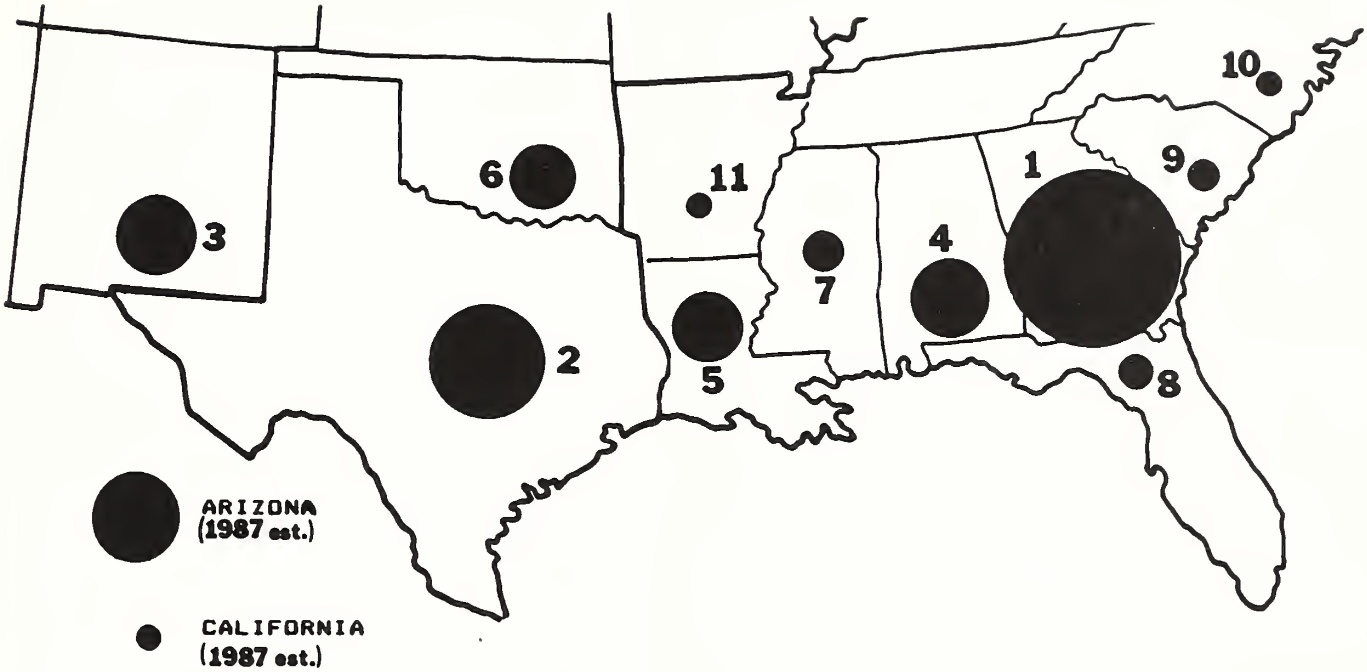

Figure 1. Relative production of pecans in major pecan producing states, 1977-1986, adapted from USDA reports. Size of dot represents relative production. Total U.S. production averaged 246 million pounds per year during this time period.

PHOTOSYNTHETIC CHARACTERISTICS OF PECAN AND TEN SPECIES OF FRUIT CROPS WITH EMPHASIS ON SUN TRACKING/NON-SUN TRACKING RESPONSES

P.C. Andersen[1]

ABSTRACT

Leaf gas exchange characteristics of pecan leaves were compared to 10 species of fruit crops under field conditions in north Florida. In full sunlight [i.e., photosynthetic photon flux (PPF) ca. 2,000 μmol m^{-2} s^{-1}] net CO_2 assimilation (A) and stomatal conductance to water vapor (g_s) were highest for pecan (A= 15.9 μmol m^{-2} s^{-1}, g_s=452 mmol m^{-2} s^{-1}), intermediate to high for peach, apple pear, grape, blackberry and fig (A= 12.1 to 14.6 μmol m^{-2} s^{-1}, g_s= 23 to 370 mmol m^{-2} s^{-1}) and low for satsuma, persimmon, blueberry and kiwi (A= 5.7 to 10.2 μmol m^{-2} s^{-1}, g_s <220 mmol m^{-2} s^{-1}). The influence of non-steady state levels of irradiance was tested on gas exchange characteristics of pecan in more detail. In response to short-term (80 to 240 sec) reductions in irradiance, A declined rapidly, g_s was not altered, and transpiration (E) decreased very slightly. At low levels of irradiance water use efficiency (WUE) was near zero and intercellular CO_2 concentration (Ci) was near ambient levels. When leaves were exposed to 50 min of continuous shade A and g_s were reduced by 50 and 10%, respectively, and Ci remained increased by ca. 40 μmol mol^{-1}. In conclusion: 1) rates of gas exchange of pecan leaves are high for a C3 woody plant and; 2) pecan may be classified as non-sun tracking species with A and g_s not tightly coupled (i.e., non constant Ci).

INTRODUCTION

The influence of light intensity on carbon gain has been researched extensively under steady state conditions in the laboratory. Although providing useful physiologic information, these data often have little relevance to what is occurring under field conditions. In nature plants are often exposed to numerous and drastic fluctuations in irradiance throughout the day as a result of intermittent cloud cover, wind-generated leaf movements and mutual leaf shading (Norman and Turner 1969, Knapp and Smith 1988, 1989, 1990).

Net CO_2 assimilation declines quickly with the onset of shade and increases rapidly with the occurrence of unobstructed sunlight; however, the stomatal response to fluctuating irradiance varies widely among species (Chazdon and Pearcy 1986, Knapp and Smith 1988, 1989, 1990, Pearcy 1988). Plants having a stomatal aperture strongly dependent on the level of irradiance are classified as "sun tracking", and those having stomatal (g_s) conductance essentially independent of short-term changes in irradiance are considered "non-sun tracking" (Knapp and Smith 1990). Little information concerning sun tracking/non-sun tracking responses is available for horticultural crops.

Rates of leaf gas exchange of pecan have been reported to be relatively high (Andersen and Brodbeck 1988, Wood 1988) or low (Crews et al. 1980, Reiger and Daniell 1988) for a C3 plant. However, leaf gas exchange of pecan in response to non steady state conditions of irradiance is not known. This information would increase our knowledge of whole tree carbon gain under field conditions.

The objectives of this study were to compare leaf gas exchange of pecan to 10 species of fruit crops and to investigate the influence of fluctuations in irradiance on gas exchange characteristics of pecan leaves.

MATERIALS AND METHODS

Experimental material. The experimental site was the University of Florida Agricultural Research and Education Center, Monticello, Florida located at 30.5 N latitude and 84 W longitude. Soil type was a Dothan loamy sand (Plinthic paleudults) containing 1% organic matter. All experiments were conducted on plants growing in the field.

Plant material. Plant material was as follows: 7-year old pecan *Carya illinoensis* (Wagenh.) C. Koch cv. Elliot], 10-year-old peach [*Prunus persica* (L.) Batsch cv. Flordaking], 9-year-old apple (*Malus domestica* Borkh. cv. Anna), 2-year-old pear (*Pyrus communis* L. cv. Flordahome), 2-year-old satsuma, (*Citrus reticulata* L. cv. Owari), 3-year-old persimmon (*Diospyros kaki* L. cv. Fuyu), 6-year-old rabbiteye blueberry, (*Vaccinium ashei* Reade

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cv. Bluegem), 4-year-old grapevine, (*Vitis* sp. cv. Suwannee), 2-year-old blackberry (*Rubus* sp. cv. Shawnee), 2-year-old fig, (*Ficus carica* L. cv. Alma), and 2-year-old kiwi, [*Actinidia deliciosa* (A. Chev) cv. Hayward]. Pecan, peach, apple, grape, blueberry, blackberry and kiwi were supplied with drip irrigation at least 3 times weekly. Satsuma and fig were supplied with overhead sprinkler irrigation at least 3 times weekly. Pear and persimmon were not irrigated; however, leaf gas exchange measurements were performed after abundant rainfall.

Leaf gas exchange of pecan and 10 species of fruit crops. Ambient and leaf chamber CO_2 and H_2O vapor concentration, air temperature (AT) and photosynthetic photon flux (PPF) were measured in the field with an Analytical Development Corporation (ADC) Model LCA-2 infrared gas analyzer, an air supply unit, and a Parkinson broadleaf leaf chamber (Analytical Development Corp Ltd., Hoddesdon, Herts., England) as described previously (Andersen and Brodbeck 1988). Calculations of net CO_2 assimilation rate (A), stomatal conductance to water vapor (g_s), vapor pressure deficit (VPD), leaf temperature (LT), transpiration (E) and intercellular CO_2 concentration (Ci) were accomplished with an ADC DL2 Datalogger and appropriate software. Leaf gas exchange was measured on recently expanded leaves from 1000 to 1400 HR on selected sunny days during late May, June or July 1988 under the following conditions: PPF= 2163 $\pm$ 30 μmol m^{-2} s^{-1}, air temperature 31.3 $\pm$ 0.9°C and vapor pressure deficits, VPD= 3.5 $\pm$ 0.3 kPa (means $\pm$ SE).

Influence of short-term fluctuations in irradiance on pecan. Gas exchange was measured on 11 June 1988, on 'Stuart' leaves exposed to fluctuations in irradiance in the following sequence: 100, 66, 33, 10 and 100% sun with each measurement sequence lasting ca. 80 sec. Different levels of PPF were achieved by placing polyethylene shadecloth of varying light transmittance over the leaf chamber with the leaf remaining in the chamber for the entire measurement sequence. Preliminary experiments of continuous measurements on leaves in 100% sun showed that gas exchange of leaves in the chamber was not altered for at least 10 min. Leaf gas exchange was also measured on interior canopy leaves (naturally shaded) under ambient levels of PPF (ca. 483 $\pm$ 21 μmol m^{-2} s^{-1}). Each measurement was replicated ten times (10 trees). Means $\pm$ SE are presented.

Influence of moderate-term fluctuations in irradiance. The effects of moderate durations of shading were tested on 'Stuart' leaves from 1000 to 1200 hr on 12 June 1988. Gas exchange was measured periodically on sun-exposed leaves for 20 min, then for 50 min after polyethylene shadecloth (30% light transmittance) was placed over the leaf. Shadecloth was then removed and measurements were continued in 100% sun for 50 min. Leaf gas exchange was determined by inserting a leaflet from each of four trees into the leaf chamber every 4 to 6 min.' Values of A, g_s and Ci were grouped for each time interval. Means $\pm$ se are reported.

RESULTS

Leaf gas exchange of pecan and 10 species of fruit crops. Ambient conditions of PPF (2050 to 2340 μmol m^{-2} s^{-1}), VPD (3.1 to 4.2 kPa) and AT (28 to 34°C) were relatively similar during gas exchange measurements of all species except blueberry (VPD= 5.5 kPa, AT= 36.8°C) (Tables 1, 2). Leaf temperatures varied from 28 to 33°C with the exception of blueberry (37°C). Leaf temperature minus AT for pecan was most negative for pecan (-1.8°C), followed by grape (-1.6°C), peach (-1.5°C) and fig (0.2°C). Species manifesting positive LT-AT differentials include apple (0.9°C), pear (0.1°C), satsuma (0.5°C), persimmon (0.1°C), blueberry (0.1°C), blackberry (0.1°C) and kiwi (2.1°C). Leaf gas exchange on adaxial leaf surfaces was negligible for all broadleaf species; hence, the stomatal pathway accounted for essentially all CO_2 depletion and water vapor loss.

Net CO_2 assimilation rate (A) varied approximately 3-fold among species (Tables 1, 2). Highest values were recorded for pecan (A= 15.9 μmol m^{-2} s^{-1}) and grape (14.6 μmol m^{-2} s^{-1}). Net CO_2 assimilation rates of apple, pear, blackberry and fig leaves were intermediate (11.6 to 13.3 μmol m^{-2} s^{-1}); and rates of satsuma, persimmon, blueberry and kiwi were relatively low (5.2 to 9.7 μmol m^{-2} s^{-1}). Values of E also varied about 3-fold among species (3.1 to 9.7 μmol m^{-2} s^{-1}), and followed a similar pattern to that of g_s. Water use efficiency was in the range of 1.4 to 2.2 for all species except blueberry (0.9) and grape (1.1).

Pecan also manifested the highest g_s of any species (452 mmol m^{-2} s^{-1}). Moderately high rates of g_s were recorded for pear, grape and apple (g_s = 338 to 368 mmol m^{-2} s^{-1}), intermediate rates (198 to 245 mmol m^{-2} s^{-1})

for pear, satsuma, persimmon, blackberry and fig and low rates (91 to 130 mmol m^{-2} s^{-1}) for blueberry and kiwi.

Intercellular CO_2 concentration varied less between species than other measurements of leaf gas exchange. The values of Ci varied from 198 to 234 μmol m^{-2} s^{-1} CO_2. Values of A were neither directly nor inversely proportional to values of Ci.

Influence of short-term fluctuations in irradiance on leaf gas exchange of pecan. Stepwise alterations in light intensity, in the sequence 100, 66, 33, 10 and 100% sun, greatly influenced CO_2 uptake, while g_s and E remained essentially constant (Fig. 1). Consequently, A and WUE were much lower, and Ci was higher at reduced levels of irradiance. Net CO_2 assimilation and WUE were near zero at 10% sun (PPF ca. 200 μmol m^{-2} s^{-1}), and Ci was near ambient CO_2 concentration. (Leaf temperature was ca. 1.6°C higher in 100% than in 10% sun and was not likely to be a major contributing factor). Net CO_2 assimilation, WUE and Ci quickly returned to initial values when leaves were re-exposed to 100% sun. Net CO_2 assimilation was also reduced more than g_s or E in leaves exposed to prolonged shade in the canopy interior (ca. 23% sun, PPF= 474 μmol m^{-2} s^{-1}; hence WUE was less and Ci was higher in shaded interior leaves compared to sun-exposed exterior leaves.

Influence of moderate-term fluctuations in irradiance on leaf gas exchange of pecan. Net CO_2 assimilation, g_s and Ci were stable for 20 min when leaves were exposed to 100% sun (Fig. 2). Shortly after the onset of shading (30% sun) A was rapidly reduced, g_s declined slightly and Ci increased. After 50 min of exposure to 30% sun (i.e., 70 min after initial measurements) A remained stable at 50% of initial values, and g_s and Ci declined gradually. With a return to full sun (i.e., 75 min) gradual increases in A and g_s, and decreases in Ci were noted. However, values of A and g_s failed to return to initial values perhaps due to increases in leaf temperature and vapor pressure deficits after return to 100% sun (See Fig. 2).

DISCUSSION

Leaf gas exchange of pecan varies considerably depending upon the nature of the plant material. Field measurements have indicated that pecan leaves have relatively high rates of leaf gas exchange. Andersen and Brodbeck (1988) reported that 'Stuart' and 'Choctaw' manifested a maximum A and glH_2O of 18 to 22 μmol m^{-2} s^{-1} and 700 to 800 mmol m^{-2} s^{-1}, respectively. Wood (1988) reported similar maximum rates (A= 16 to 18 μmol m^{-2} s^{-1}, g_s= 600 to 900 mmol m^{-2} s^{-1}) on 'Desirable' trees. These results contrast sharply with data from excised 'Stuart', 'Mobile' and 'Brooks' branches in the laboratory (Crews et al. 1980) (maximum A= 8.5 μmol m^{-2} s^{-1}), and from a study of containerized 'Curtis' seedlings in the greenhouse (maximum g_s = 160 mmol m^{-2} s^{-1}) (Rieger and Daniell 1988). Previous work performed in the field has shown that pecan was not inhibited at LT= 41.5°C, PPF= 2000 μmol m^{-2} s^{-1} and VPD= 3kPa (Andersen and Brodbeck 1988). This was ascribed to a relatively high hydraulic conductance for pecan compared to most other woody species (Andersen and Brodbeck 1988, Steinberg et al. 1990). Transpiration rates and WUE reported in Table 1 are similar to previously published reports (Andersen and Brodbeck 1988, Wood 1989). The 10 remaining species of fruit crops manifested lower maximum rates of leaf gas exchange than pecan. A comparison to previously reported values appears elsewhere (Andersen 1989).

Although intermittent cloud cover invariably has a rapid effect on A, some plant species undergo rapid stomatal closure ("sun tracking") while other species maintain a relatively constant aperture in sun or shade ("non-sun tracking") (Mooney et al., 1983; Knapp and Smith 1987, 1988, 1989, 1990). Our data indicate that pecan with adequate soil moisture is a non-sun tracking species. Steady state measurements of g_s were lower in shade than in full sunlight (Fig. 3) indicating that the lack of stomatal closure short-term (Fig. 1) and moderate-term (Fig. 2) reductions in irradiance was due to slow guard cell adjustments, and not because g_s was at maximum values at low levels of PPF (Fig. 3).

A consequence of a non tracking response to intermittent cloud cover is a great reduction in WUE. A potential disadvantage of a non-tracking response includes a more rapid depletion of soil water which may eventually translate to increased plant moisture stress. Conversely, assuming adequate soil moisture levels, a non-tracking response maximizes carbon gain during the period of reduced irradiance and after a return of full sunlight as a consequence of elevated Ci (Mansfield et al. 1990). The low WUE occurring in interior canopy leaves is compounded by the fact that older leaves which are often located in the canopy interior gradually become insensitive (i.e., do not close) in response to a reduction in water potential (Andersen and Brodbeck 1988).

Disproportionate reductions in A compared to g_s in leaves exposed to short-term reductions in irradiance (Fig. 1), in naturally-shaded leaves located in the canopy interior (Fig. 1), and in leaves after 50 min exposure to 30% sun (Fig. 2) resulted in a 30 to 60 μmol^{-1} increase in Ci. Similar increases in Ci have been reported in leaves of *Helianthella quinquenervis* and *Senecio triangularis* exposed to simulated cloud cover (Knapp and Smith 1988). Thus, photochemical reactions in the chloroplast responded rapidly to changes in irradiance compared to turgor-mediated guard cell adjustments (Nobel 1983). While anatomical, physiological, and biochemical mechanisms involved in shade acclimation of pecan are complex and poorly understood, feedback inhibition from adjacent leaves did not play a major role in acclimation since there was no effect of shading or removal of adjacent leaves (data not shown). This suggests that acclimation to irradiance is solely based on the light microclimate of each individual leaf or leaflet.

The response of pecan leaves to shading are at variance with the strong positive correlations between A and g_s (and constant Ci) that have been reported for many herbaceous species (Dubbe et al. 1978, Farquhar et al. 1978, Wong et al. 1979, 1985a, 1985b, 1985c). However, Ci has been altered in leaves as a function of: Nutrition in peach [*Prunus persica* (L.) Batsch] (DeJong 1982); ABA treatment in grapevine (*Vitis vinifera* L.) (Downton et al. 1987); VPD, leaf temperature and PPF in olive (*Olea europaea* L.) (Bongi et al. 1987), blueberry (*Vaccinium* spp.), (Moon et al. 1987) and grapevine (Downton et al. 1987). Downton et al. (1988) showed that patchy stomatal closure may result from exogenous ABA application which, may in turn, result in erroneous calculations of Ci. The amount of error is proportional to the degree of nonlinearity of A and g_s (Mansfield et al. 1990). Nevertheless, fluorescence data confirmed that Ci was more variable than previously assumed (Downton et al. 1988).

In conclusion, rates of leaf gas exchange of pecan are high for a C3 woody species. Net CO_2 assimilation and g_s were not strongly coupled in pecan leaves (i.e., a fixed level of Ci was not maintained) under conditions of non-limiting soil moisture, in response to fluctuations in irradiance, or in leaves exposed to prolonged periods of shade. A consequence of the weak coupling between A and g_s in pecan leaves is to maximize carbon gain at the expense of increased water loss. With the development of plant moisture stress a tighter coupling of A and g_s may occur (Knapp and Smith 1990).

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Table 1. Leaf gas exchange characteristics of persimmon (cv. Fuyu), blackberry (cv. Bluegem) grape *Vitis* sp. (cv. Suwanee), *Rubus* sp. (cv. Shawnee), fig (cv. Alma) and kiwi (cv. Hayward) under field conditions in north Florida.

	Species					
Variable	persimmon	blueberry	grape	blackberry	fig	kiwi
PPF (μmol m^{-2} s^{-1})[z]	2106 ± 44[y]	2305 ± 60	2114 ± 67	2120 ± 37	2165 ± 63	2200 ± 78
VPD (kPa)	3.7 ± 0.1	5.5 ± 0.1	3.6 ± 0.1	3.3 ± 0.1	3.3 ± 0.1	4.1 ± 0.1
AT (°C)	30.1 ± 0.1	36.8 ± 0.1	34.3 ± 0.3	29.0 ± 0.1	28.4 ± 0.3	28.1 ± 0.2
LT (°C)	30.2 ± 0.2	36.9 ± 0.2	32.7 ± 0.4	28.9 ± 0.1	28.6 ± 0.3	30.2 ± 0.2
A (μmol m^{-2} s^{-1}	7.6 ± 0.5	5.2 ± 0.4	14.6 ± 0.5	11.9 ± 0.6	12.1 ± 0.5	6.2 ± 0.4
E (mmol m^{-2} s^{-1}	5.4 ± 0.2	6.0 ± 0.2	9.3 ± 0.2	5.7 ± 0.3	5.6 ± 0.3	3.1 ± 0.2
WUE (mmol CO_2 mol H_2)	1.39 ± 0.05	0.86 ± 0.04	1.06 ± 0.04	2.08 ± 0.07	2.20 ± 0.11	2.00 ± 0.06
g_s (mmol m^{-2} s^{-1}	201 ± 18	130 ± 3	361 ± 9	245 ± 21	243 ± 20	91 ± 7
Ci (μmol mol^{-1})	236 ± 3	232 ± 4	215 ± 2	205 ± 6	198 ± 7	198 ± 4

[z]Abbreviations: PPF=photosynthetic photon flux, VPD=vapor pressure deficit, AT=air temperature, LT=leaf temperature, A=net CO_2 assimilation rate, E=transpiration rate, WUE=water used efficiency, g_s=leaf conductance to water vapor, Ci=intercellular CO_2 concentration.
[y]Reported values are means ± 1 SE; persimmon n=12, blueberry n=13, grape n=14, blackberry n=13, fig n=12 and kiwi n=12.

Table 2. Leaf gas exchange characteristics of pecan (cv. Elliot), peach (cv. Flordaking), apple (cv. Anna), pear (cv. Flordahome) and satsuma (cv. Owari) under field conditions in north Florida.

	Species				
Variable	pecan	peach	apple	pear	satsuma
PPF (μmol m^{-2} s^{-1})[z]	2083 ± 43[y]	2251 ± 26	2243 ± 39	2049 ± 48	2053 ± 65
VPD (kPa)	3.1 ± 0.1	3.5 ± 0.1	3.6 ± 0.2	3.5 ± 0.1	3.2 ± 0.1
AT (°C)	33.4 ± 0.1	34.0 ± 0.2	32.9 ± 0.2	30.0 ± 0.3	27.6 ± 0.2
LT (°C)	31.6 ± 0.2	32.5 ± 0.3	32.0 ± 0.7	29.7 ± 0.3	28.1 ± 0.3
A (μmol m^{-2} s^{-1}	15.9 ± 0.3	13.3 ± 0.3	11.6 ± 0.6	11.8 ± 0.4	9.7 ± 0.6
E (mmol m^{-2} s^{-1}	9.7 ± 0.1	9.3 ± 0.2	8.6 ± 0.2	5.7 ± 0.1	4.8 ± 0.3
WUE (mmol CO_2 mol H_2)	1.63 ± 0.04	1.45 ± 0.04	1.35 ± 0.06	2.10 ± 0.04	2.02 ± 0.04
g_s (mmol m^{-2} s^{-1}	452 ± 7	368 ± 12	338 ± 12	222 ± 8	198 ± 16
Ci (μmol mol^{-1})	223 ± 2	227 ± 2	234 ± 4	200 ± 1	212 ± 3

[z]Abbreviations: PPF=photosynthetic photon flux, VPD=vapor pressure deficit, AT=air temperature, LT=leaf temperature, A=net CO_2 assimilation rate, E=transpiration rate, WUE=water used efficiency, g_s=leaf conductance to water vapor, Ci=intercellular CO_2 concentration.
[y]Reported values are means ± 1 SE; pecan n=18, peach n=31, apple n=10, satsuma n=11.

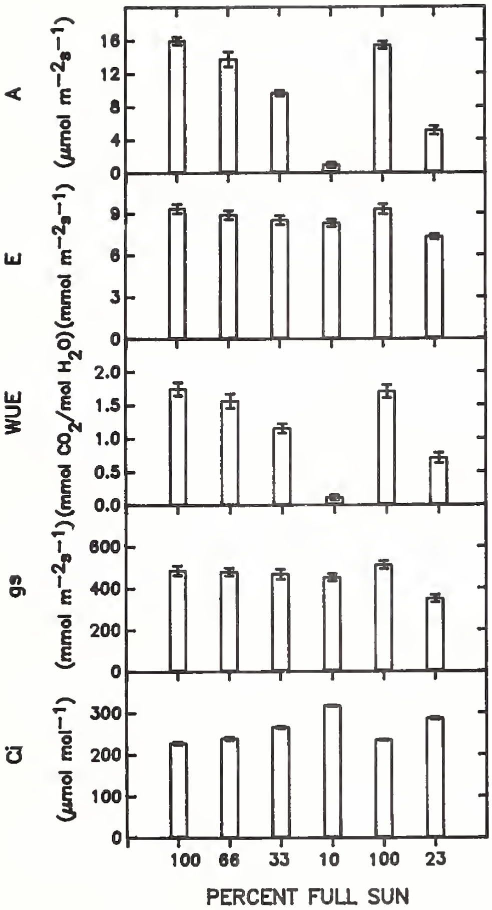

Figure 1. Net CO_2 assimilation (A), transpiration (E), water use efficiency (WUE), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) of 'Stuart' pecan leaves exposed to 100 (PPF = 2120 $\pm$ 14.5 μmol m^{-2} s^{-1}), 66, 33, 10 and 100% sun with each sequence lasting ca. 80 sec. The last column (i.e., 23% fill sun; 483 + 21 μmol m^{-2} s^{-1}) represents the natural irradiance level of leaves measured in the canopy interior. Error bars correspond to mean $\pm$ SE, n = 10. Leaf temperatures were 30.4 $\pm$ 0.8, 29.5 $\pm$ 0.8, 29.0 $\pm$ 0.9, 28.8 $\pm$ 0.7, 29.8 $\pm$ 0.8 and 29.1 $\pm$ 0.6°C (mean $\pm$ SE) for the 100, 66, 33, 10, 100 and 23% sun treatments, respectively. Vapor pressure deficits were 1.9 $\pm$ 0.1, 1.7 $\pm$ 0.1, 1.6 $\pm$ 0.1, 1.5 $\pm$ 0.1, 1.9 $\pm$ 0.1 and 1.8 $\pm$ 0.1 kPa for the 100, 66, 33, 10, 100 and 23% full sun treatments, respectively.

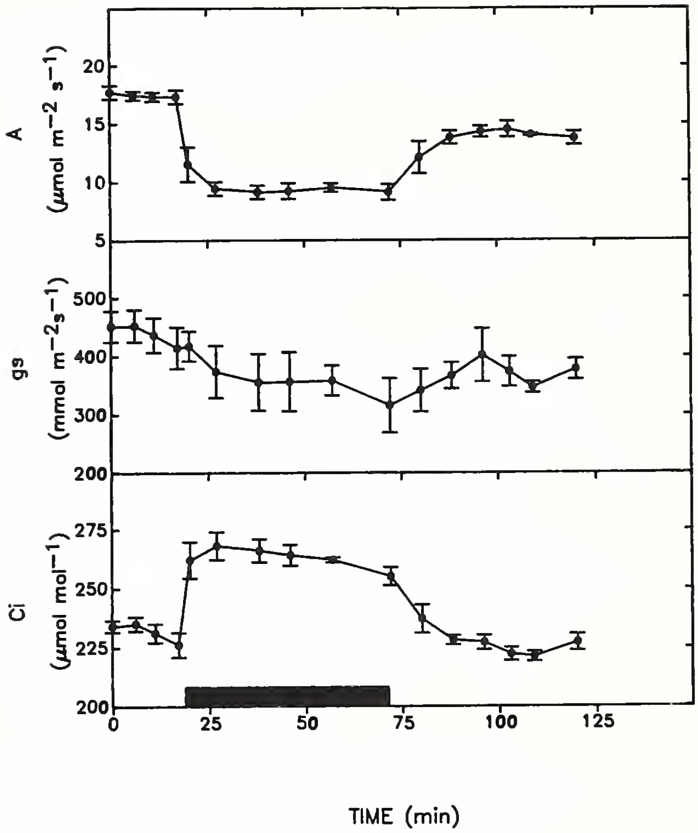

Figure 2. Effect of variable sunlight on net CO_2 assimilation (A), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) of 'Cape Fear' pecan leaves. Leaves were exposed to 20 min of 100% sun (PPF= 1924 $\pm$ 24 μmol m^{-2} s^{-1}), then 50 min of 33% sun (PPF= 583 $\pm$ 10° μmol m^{-2} s^{-1}) represented by the darkened horizontal bar, then 50 min of 100% sun. Circles and error bars represent means $\pm$ SE, n = 4. Leaf temperatures were 29.0 $\pm$ 0.2, 30.7 $\pm$ 0.3 and 35.1 $\pm$ 1°C (mean $\pm$ SE) for the 100, 30, and 100% sun period, respectively. Vapor pressure deficits were 2.2 $\pm$ 0.1, 2.2 $\pm$ 0.1 and 3.3 $\pm$ 0.1 kPa for the 100, 30 and 100% sun period, respectively.

EFFECT OF THE POLLEN PARENT ON FERTILIZATION SUCCESS

Robert D. Marquard[1]

ABSTRACT

Examples of pollen competition and selective fruitlet abortion were presented from the literature. Preliminary data demonstrates similar events likely occur in pecan. That is, pollen germination and tube growth is temperature dependent and a genotype by environment interaction may exist. A northern pollen source tended to germinate and grow slightly better than a southern pollen source at lower temperatures. Some pollen types appear to grow more vigorously *in vivo* than others which may impart some selective advantage in fertilization success. A disequilibrium was found in the rate of fertilization success when a mixture of four pollen parents was used to pollinate 'Cheyenne'.

INTRODUCTION

Pecan pollination occurs in the spring and little thought is given to the phenomena beyond the requirement that pollen must be present during stigma receptivity. If stigma receptivity overlaps with pollen shed, pollination is effective, fertilization occurs, and a successful pecan crop likely will be produced. One common criterion to select a pollenizer cultivar is that it has a complimentary dichogamy pattern to the main crop cultivar. However, fertilization success of different pollen types and eventual fruit maturity are not necessarily random events. Several examples with other plants illustrate this point.

Avocados have extremely high rates of fecundity and an individual tree may produce 10^6 perfect flowers. However, only several hundred fruit typically reach maturity. Are there mechanisms that selectively influence which fruit mature? Degani and co-workers (1986) presented clear evidence that fruitlet abortion in avocado is linked to a scorable biochemical marker and therefore has a genetic component. Maturing and aborted avocado fruit were genotyped for one gene controlling leucine aminopeptidase (*lap-2*). The 'ss' genotype of *lap-2* was detectable in both immature and aborted fruit but never was found among mature fruit.

Secondly, the degree of competition among pollen can effect plant performance in future generations. For example, the size of the pollen dose used in controlled pollinations (either a large or small dose of pollen applied to the stigma) can influence plant performance. Davis and co-workers (1987) demonstrated a high pollen dose resulted in "superior" squash seed. Characteristics used to determine seed superiority were plant performance for fruit weight, seed per plant, days to first flower, and initial germination rate.

Mulcahy and Mulcahy (1975) showed carnation seedlings, resulting from pollinations made more distal to the ovary, germinated more quickly and grew faster than seed derived from pollinations made more proximal to the ovary. The more distal pollinations created greater competition among pollen by forcing pollen tubes to grow a longer distance to reach the micropyle. Furthermore, some attributes of vigor (originating in the gametophytic pollen) were conferred to the sporophytic seedling! Expression of genes in the gametophyte that overlap is the sporophyte has been estimated to be about 60% (Tanksley et al., 1981).

EXAMPLES OF POLLEN COMPETITION IN PECAN

Pollen competition and selective abortion of pecan fruit does occur. An extreme example of selective abortion involves interspecific hybridization. Early *in vivo* growth of some hickory pollen (i.e., *C. myristiformis* and *aquatica*) on pecan stigmas is not inferior to pollen tube growth after conspecific pollination of pecan (Figure 1). However, seed set is generally low after interspecific crosses of *Carya* are made (personal obs.). Therefore, some mechanism reduces the frequency of hybridization among *Carya* species.

Normal fruitlet abortion in pecan is moderate and is estimated to range from 20 to 50 percent (Sparks and Madden, 1985). A more subtle example of selective abortion involves selfed pecan fruit. Self-pollination is responsible for a

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small but real fruitlet drop (e.g., the third drop) (Sparks and Madden, 1985). In addition, selfed fruit that do mature typically have less volume and kernel weight than cross-pollinated fruit (Romberg and Smith, 1946; Marquard, 1988a). Perhaps, the maternal parent "recognizes" the genetic liability of selfed fruit and aborts a greater percentage and/or allocates less resources (i.e., carbohydrates) to those developing fruit. Temme (1986) suggests many factors can explain variability in seed weight and that "detectable genetic variation (should) be added to the list of (possible) factors...".

Supplemental pollination of pecan could be considered under at least two conditions. First, if pollen production in a given orchard is expected to be relatively low, additional pollen could enhance effective pollination and nut set. Secondly, if an orchard is composed of a single cultivar, selfing may predominate, and fruit quality may be reduced. Supplemental pollination in the second case likely will be ineffective for three reasons. First, peak receptivity is not easily determined and only a portion of the female flowers will be receptive at any one time. Second, time of pollen deposition can significantly influence fertilization success. Pollen that first impacts the stigma has a decided disadvantage over later arriving pollen.

Bagged flower clusters were pollinated twice with two different pollen parents. Pollinations were separated temporarily to evaluate the influence of timing of pollen deposition. Pecan pollen that arrived 4 and 24 hours after initial pollen impaction had about a 40 and 3% chance, respectively, for fertilization success (Figure 2). Because of temporal differences in pollen deposition, one pollen type is given a competitive advantage. However, these data demonstrate that fertilization success strongly favors the first pollen to arrive on the receptive stigma.

Thirdly, a supplemental release of pollen may be greatly diluted by a high background of native pollen in the orchard thereby reducing the probability of success. As a first approximation, 50 grams of pollen per acre has been recommended as a suitable dose of pollen (McClure, 1986). That quantity can be extracted from 2.5 gallons of properly collected catkins which can easily be gathered from a single tree.

Supplemental pollination by fixed wing aircraft over a solid block of 'Western' resulted in fertilization success of 10-17% (Marquard, 1988b). Twenty-eight grams of pollen were applied per tree and equates to about 1,300 grams of pollen per acre (at 10m x 10m spacing) which is likely uneconomical in most situations.

I have also evaluated pollen competition among four types used simultaneously in a pollen mixture. A mixture of pollen was prepared and used in controlled pollinations with 'Cheyenne' as the maternal parent. Four pollen parents were chosen so that each could be uniquely identified as the paternal parent in mature fruit using two heritable biochemical markers (Marquard, 1987). Each pollen source in the mixture was equally represented by weight. 'Cheyenne' pollen and three cross-pollen types were used in the mixture and paternity was identified in each mature fruit. Assuming percent germinability of each pollen parent was equal and fertilization success is random, then the fertilization success of each pollen parent should be about 25 percent. The logic and biochemical markers used to evaluate paternity is shown in Table 1. Progeny showed a skewed distribution in the success rate of each paternal parent. Apparently, self-pollen failed to effectively compete with cross-pollen types whereas two cross-pollen parents showed high fertilization success (Table 1). Pollen used in this work was collected the same day and treated identically. Unfortunately, percent germination of each pollen parent could not be reliable determined at the time of the experiment. However, these data suggest fertilization success may not be a random event if more than one pollen parent simultaneously impacts the stigma. Also noteworthy, the most successful cross-pollen parent produced the double heterozygous condition for the two scorable biochemical markers that were used (Table 1).

Differences in pollen tube growth rate among pollen parents also could skew fertilization success. All possible combinations of crosses were made among 'Western', 'Cape Fear', and 'Cheyenne' cultivars and *in vivo* growth of pollen tubes was evaluated four hours post-pollination. From one years date, 'Cape Fear' pollen grew more quickly than the others (Figure 3). These faster growing types may have an early competitive advantage that results in a higher rate of fertilization success. In addition, self-pollen did not appear to be disadvantaged within the time frame of this study (Figure 3).

Finally, the rate of vivipary (i.e., preharvest germination) in pecans can be influenced by the pollen source. Ou et al., (1990) made various controlled crosses and demonstrated that a more

northern pollen source (i.e., 'Johnson') yielded fruit that were slower to germinate than fruit with a more southern paternal parent (i.e., 'Cherokee'). Pollen tube growth is temperature dependent and I have rarely observed *in vitro* pollen germination below 17°C or above 32°C. Optimum germination and tube growth occurs at about 23-29°C (Figure 4). The ability of 'Gibson' and 'Cape-Fear' pollen to germinate and grow was simultaneously evaluated on a solid media at various temperatures. Preliminary data suggests northern 'Gibson' pollen performs slightly better at lower temperatures and has a lower temperature optimum for tube growth than 'Cape-Fear' pollen. If there is a genotype by environment interaction, southern pollen may have a selective advantage at higher ambient temperatures where vivipary is more likely to occur.

CONCLUSION

Selective abortion of fruit and pollen competition exists in other plant species and this paper demonstrates that similar mechanisms likely exist in pecan. Since the pollen parent can influence nut quality in pecan, selection of pollenizer cultivars to maximize production may be more complex than simply selecting cultivars with complimentary dichogamy patterns.

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Table 1. Equal portions of four pollen parents were mixed and used in controlled pollinations of 'Cheyenne' to evaluate competition among pollen types. Each pollen parent was selected for it's unique genotype using two biochemical markers [malate dehydrogenase - 1 (*Mdh-1*) and phosphoglucose isomerase - 2 (*Pgi-2*)]. Pollen parent of each mature fruit could thereby be determined. Genotypes of possible parents and progeny given.

	Mdh-1	*Pgi-2*
Cheyenne	(bb)	(bb)

Possible Pollen Parent	*Mdh-1*	*Pgi-2*	Progeny genotypes *Mdh-1*	Progeny genotypes *Pgi-2*	Percent fertilization success
Self	(bb)	(bb)	(bb)	(bb)	1
Cross 1	(bb)	(aa)	(bb)	(ab)	14
Cross 2	(aa)	(bb)	(ab)	(bb)	34
Cross 3	(aa)	(aa)	(ab)	(ab)	51

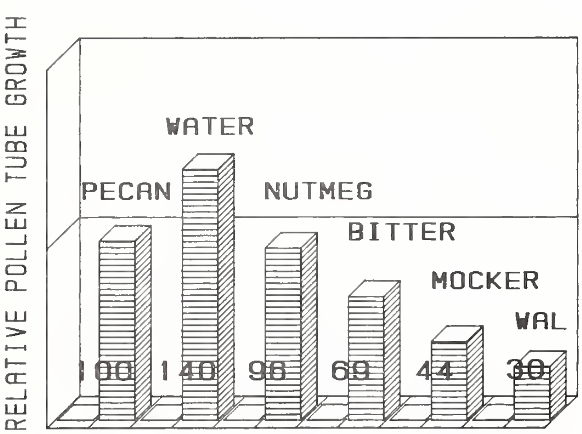

Figure 1. Relative growth rate of various pollen sources on pecan stigmas. Pollen sources included: pecan (*Carya illinoensis*), waterhickory (*C. aquatica*), nutmeghickory (*C. myristiformis*), bitternut hickory (*C.cordiformis*), mockernut hickory (*C. tomentosa*) and one walnut species (*Juglans macrocarpa*).

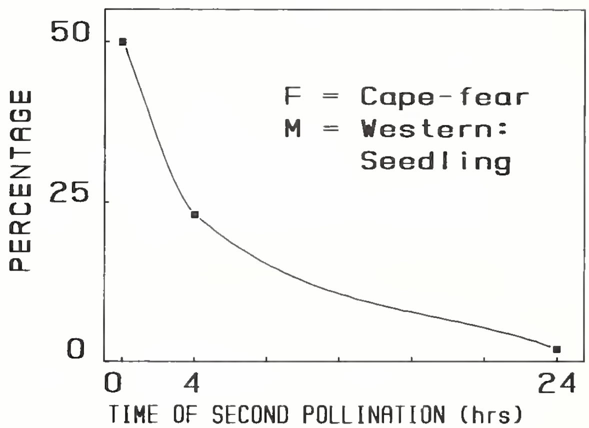

Figure 2. Percentage of mature fruit with 'Western' as a paternal parent. At time zero, 'Western' and a seedling pollen were applied simultaneously to receptive female flowers of 'Cheyenne'. All remaining female clusters were initially pollinated with the seedling pollen followed four or 24 hours with 'Western' pollen. Paternity in mature fruit was determined by genetic markers.

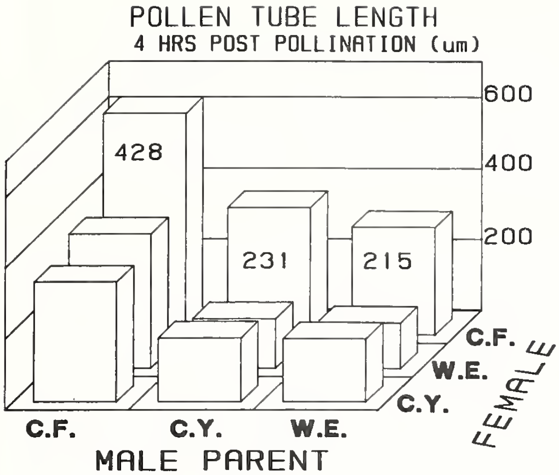

Figure 3. All possible combinations of controlled pollinations were made between 'Western', 'Cape Fear' and 'Cheyenne'. Stigmas were harvested four hours post-pollination and pollen tube length was determined by UV miscroscopy.

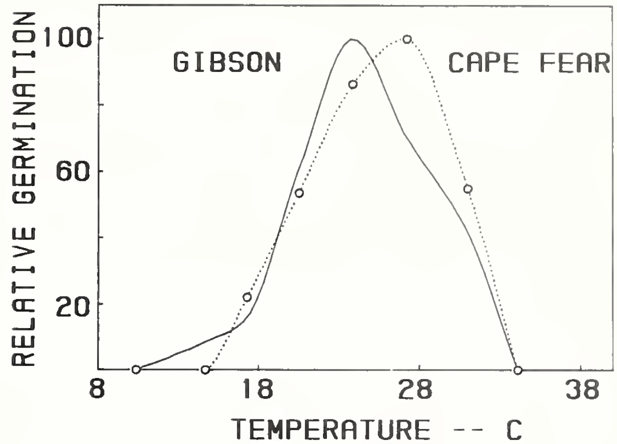

Figure 4. Relative rate of pollen germination of 'Gibson' and 'Cape Fear' pollen at various temperatures.

ALTERNATE BEARING OF PECAN

Bruce W. Wood[1]

This workshop has been structured to provide a forum for the presentation of new knowledge, the interpretation of both old and new knowledge, and for speculation or extrapolation of what everything means. Since speculation is a cornerstone to the advancement of science, I have elected to take advantage of this opportunity to theorize concerning alternate bearing, a major horticultural problem. That is found to some degree in essentially all producing orchards.

The nature of pecan to alternately produce nut crops is a major problem for most people associated with the cultivation or marketing of pecans. It causes economic problems for growers and suppresses domestic and foreign markets. The problem is genetically based and affects both production and quality (i.e., yield).

Growers and scientists alike have been only partially successful in their attempts to reduce the deleterious impact of alternate bearing on the pecan industry. This is partially due to approach, which can be summed up by the words of a great American philosopher:

> "For every thousand that chops away at the leaves of evil [or a problem] there is only one that strikes at the root," (H.D. Thoreau).

While extensive efforts have been made to eliminate alternate bearing, such efforts have traditionally focused on "chopping away at the leaves" and have not been able to effectively "strike at the root". Cultural inputs such as water, pruning, spacial arrangement, nutrient elements and pest control have "chopped off a lot of leaves" and have subsequently gone a long way in reducing the severity of the problem. However, most such inputs are expensive and have helped to create a crisis situation that has resulted in growers being caught in a severe "cost-price squeeze". The economic stresses of alternate bearing can likely be reduced as growers and scientists alike acquire a better understanding of the nature, or "root", of the problem.

This report is presented with the purpose of providing a conceptual tool, or working hypothesis, for growers and scientists in their efforts to reduce the economic impact of the alternate bearing problem and to provide a functional understanding of the problem to the nonhorticulturist (who make up the bulk of the pecan scientists in the U.S.). It should assist in efforts to moderate the impact of alternate bearing on the pecan industry by helping to reveal the "root" and to identify strategies to attach **at or near to the root**. I have elected to exclude an exhaustive literature review since the objective is to propose a functional concept rather than to provide a critical evaluation or reformulation of existing research results.

Since theories are typically modified as knowledge is acquired, the following concepts on alternate bearing are no exceptions. The reader is reminded that, within the **realm of nature**, it is impossible to **absolutely** prove anything [Our lack of absolute knowledge (or lack of knowledge that we have absolute knowledge if ever we were satisfied that we had absolute knowledge) regarding the true nature of the space-time continuum and its interaction with the multidimensional matrix of matter, energy and fundamental forces obviously precludes **absolute proof** and only allows proofs within limits defined by logic or apparent reality]. As scientists, we make objective observations of natural phenomenon, apply deductive and inductive reasoning to these observations and then formulate a theory that explains the phenomena. The theory is then verified by testing its predictions. These predictions, or hypotheses, are then objectively tested to see if they can be disproven (since a hypothesis can not be proven). A theory is therefore subject to continual revision as more information is acquired. The theory presented in this discussion on alternate bearing should be expected to be altered and/or refined, and subsequently better explain reality, as more information becomes available. Even though it obviously possesses a degree of error, most of the observed phenomena associated with alternate bearing are reconciled. Thus, the theory can function as a conceptual tool which would allow growers and scientists alike to strike closer to, or perhaps in the vicinity of, the root of the alternate bearing problem.

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Background

There are several concepts that require a degree of understanding before alternate bearing can begin to be understood. These are the concepts of 'Definition', 'Nature', and 'Compartmentalization'.

Definition. An understanding of alternate bearing begins with the recognition of the symptoms of the problem. For purposes of this discussion, alternate bearing is defined as the alternation of nut yield (encompassing both quantitative and qualitative factors) from one crop year to the next. The intensity, or magnitude, can vary from year-to-year, with cultivar, with environmental stresses, etc. It can be mathematically described (or approximated) in many different ways using quantities such as 'B', 'I', 'R', 'K', 'K^2' and 'E' which identify and emphasize specific characteristics of alternate bearing (Pierce and Dobersek-Urbanc 1967).

Alternate bearing is often confused with 'biennial' or 'irregular bearing' (Monselise and Goldschmidt 1982). Alternate bearing is, in fact, a general term referring to qualitative and/or quantitative alterations in yield. Within this context 'biennial', 'triennial', 'quadennial', 'irregular' are all special types of alternate bearing. Absolute 'irregular bearing' means that there must be a yield pattern devoid of symmetry, or is totally random (Mish 1986); for example, production from year to year, or for a set of years, to another set of years is without any degree of cycling or periodicity. Since absolutes regarding phenotypic expression within the biological world are rare, alternate bearing should therefore be expected to take on a degree of irregularity; or rather, 'irregular bearing' can exhibit a weak 'alternate bearing' pattern (yield alternating from one year to the next).

Pecan trees exhibit a strong tendency to bear 'irregularly'; however, the term is generally not as precise a descriptor as is 'alternate bearing' because the perceived irregularity has in fact a regularity, which is usually evident only over long time periods (e.g., 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 year cycles). Under these circumstances of 'triennial', 'quadennial', etc. cycles, the 'irregular' terminology is obviously inaccurate.

The term 'alternate', 'biennial', and 'irregular' bearing are all appropriate for describing fruit production in pecan trees or orchards under certain circumstances; however in general, 'biennial bearing' possesses the greatest degree of accuracy for describing production cycles at the shoot, limb, tree and orchard levels, however a better terminology would be 'periodic bearing' because pecan produces on cycles of different periods. 'Irregular bearing' is best utilized in reference to apparent irregular variations within the various bearing cycles.

'Biennial bearing' is a special case of 'alternate bearing'. Production patterns at state, regional, and multiple-regional levels can usually be characterized as 'biennial bearing' because there is usually a two-year cycle evident in the long-term yield history (Wood et al. 1991, Gemoets et al. 1976). For example, seedling nut production in Oklahoma exhibits a strong 2-year cycle. Such a pattern would fit the definition of 'biennial bearing', as a specific type of 'alternate bearing'. U.S. production of both cultivar and seedling class pecans possesses a 'biennial' tendency because there is a statistically significant 2-year-cycle, however the cycle is blurred, having a degree of irregularity due to complex interactions (Wood et al. 1991; unpublished observations).

Alternate bearing is a phenomena existing at several levels. It exists at the shoot level (Level I) as a purely biological property, limb (Level II) and tree (Level III) levels it exists as an interaction of biological and statistical properties. At the orchard (Level IV), regional (Level V), and multi-regional (Level VI) it exists as an averaged statistical or mathematical echo of the biological units. 'Biennial bearing' is the most pronounced type of alternate bearing at Levels I-IV, but is less pronounced at Levels V or VI; additionally, its intensity diminishes as level increases. Variability in production at the regional and national levels (multi-regional) usually can be termed 'cyclic bearing' since a statistical symmetry (or periodicity) of various periods does exist (Wood et al. 1991, Geomets et al. 1976).

It is common for growers, and sometime for scientists also, to classify pecan groves or orchards as 'non-alternate bearing' if the planting produces a relatively stable overall yield of nut crops. This characterization is partially true; however it is deceptive, and if misunderstood it can cost growers money. What is commonly not comprehended by some growers is the fact that, within such plantings, each individual tree is on a unique bearing pattern. An orchard comprised of individual trees on non-sychronous cycles produces relatively stable nut yields from year to year; however, the variability in nut quality (hence lower income) is high (Sparks

1974). Therefore, alternate bearing trees, within an otherwise stable yielding orchard, cause substantial revenue losses due to excessive variability in factors that affect nut quality. This loss in quality also translates into marketing related problems for the pecan industry.

Nature. Alternate bearing is a natural expression of most forest and fruit tree species, especially those producing medium to large fruits which ripen in late summer or early autumn (Monselise and Goldschmidt 1982). Trees of such species inherently bear on cycles ranging from 2-15 years. This reproductive trait is probably an adaptive advantage for long-lived trees in the wild insomuch that it likely increases the probability of a tree producing offspring that survive predation (inconsistent masting generally acts to suppress populations of seed consuming animals). Hence, annually bearing trees are probably at a selective disadvantage in the natural habitat. Even though it is an advantage in the wild, alternate bearing is distinctly undesirable in agriculture. Pecan is a relatively new crop with the majority of significant cultivars originating either as selections from wild trees or as selections only a couple of generations removed from the wild (Wood et al. 1990). There has not yet been enough biological domestication to result in cultivars that bear annually with only minor fluctuation in yield (an interaction between production and quality traits). The artificial selection pressures exerted by the USDA-ARS pecan breeding program is anticipated to eventually provide stable-yielding cultivars; meanwhile, the problem is best addressed by avoiding the cultivation of cultivars possessing a propensity for moderate to major oscillations in yield and to implementing cultural and pest management practices which moderate this phenomenon.

Compartmentalization. Pecan trees appear to naturally exhibit the characteristic of 'compartmentalization' (Figure 1) so typical of forest trees. Young trees are generally comprised of but a single compartmental unit. This means that organic molecules move more or less freely among all sectors of the tree's organs. As a tree grows, the degree of compartmentalization within the tree increases insomuch that certain major limbs and roots become closely affiliated physiologically with each other. These units appear to be largely nonexistent as far as the transport of nutrient elements and water is concerned, however they appear to be distinct realities for the transport of organic assimilates. The number of units and degree of compartmentalization (or autonomy) increase with tree size (personal observation). The relationship is probably more closely associated with tree size than tree age. Large trees, such as 60+ year-old-trees, are usually comprised of several (3-12+) distinct compartments. The result is that such trees are in actuality a composite organism made up of several physiologically distinct and quasi-autonomous entities which largely (from the standpoint of alternate bearing) behave as physiologically independent units. Again, physiological compartmentalization is minimal in small trees and becomes increasingly entrenched as trees enlarge. This compartmentalization results in the alternate bearing phenomena being expressed within these units; hence, small trees do not exhibit multiple alternate bearing units (i.e. major branches) whereas large trees are comprised of several alternate bearing units. These units may bear alternately 'in phase' or 'out of phase'. Major environmental stresses (such as winter cold, spring freezes, summer drought, cloudy growing season, severe disease or insect pressure, etc.) act to synchronize the compartmental units of large trees (and trees within orchards and orchards within regions), and therefore results in all major limbs of the entire tree being 'in-phase'. However, it is common for large trees to have one or more major limbs that are 'out of phase' with the rest of the tree (i.e. one or two limbs are 'on' while the rest of the tree is 'off', or vice versa).

General Alternate Bearing Mechanism

The impact of assimilate reserves on flowering or fruit-set appears to be mediated within the compartmental unit via alterations in endogenous growth regulating chemicals and/or growth regulating receptors. Endogenous plant growth regulating substances (such as hormones) appear to be associated with the perception and regulation of carbohydrate use; however, it is carbohydrates that are the basic regulators. Subjective and objective observations provide evidence that there is a critical amount, or level, of assimilate reserves that must be available before a floral meristem can develop to produce a ripe nut (Wood 1989, Worley 1979a, 1979b, Smith et al. 1986, Smith and Waugh 1938, Malstrom and McMeans 1982). This level varies with tree development (or age) and is closely associated with the interaction between 'sink and source' (generally the ratio of fruit number to leaf area) tissues (Sparks and Brack 1972). Factors which promote the accumulation of photo-assimilates have a strong tendency to also reduce the severity of

alternations in production and quality; hence a photoassimilate and their derivatives appear to play a key regulating role.

The following is a theory that I believe generally accounts for alternate bearing behavior in pecan. While it is not particularly novel, it does for the first time provide a formal statement of the general mechanism.

> The phenotypic expression of alternate bearing (periodic alterations in flowering and/or nut-set) is regulated at the physiological level by the genetic and environmental factors influencing the quantitative and qualitative characteristics of assimilate reserves within a physiologically autonomous compartmental unit during each of two distinct regulatory phases of flower and fruit development - these being the 'Assimilate Reserve' and 'Assimilate Production' phases.

The primary assimilate factors are carbohydrates (most likely sugars and starch); however, several other storage biochemicals undoubtedly contribute to the regulation of critical developmental processes. Production periodicity is regulated primarily by the availability of photoassimilates during each of two critical physiological phases within a physiologically distinct compartmental unit. These phases are described as follows: The primary phase is the 'Assimilate Reserve Phase' (ARP) and occurs in late winter to early spring and regulates the expression and development of floral meristems (Figure 2). The availability of storage photoassimilates (especially starch) during this period determines the short-term fate of developing flowers (Wood 1989, Worley 1979b, Smith and Waugh 1938). A second critical period is termed the 'Assimilation Production Phase' (APP), and occurs at the time of kernel or cotyledon development and therefore largely regulates nut quality (Figure 3). The driving force behind the availability of photoassimilates is the relationship between kernel strength (a function of nut number and volume) and source strength (a function of leaf number, area, and physiological status) (Wood 1988). The interaction of this source-sink relationship with environmental stresses also influences the availability and utilization of assimilates, developmental processes and biochemical and physiological processes (Wood et al. 1987; Dutcher et al. 1985). The ARP and APP states encompass action thresholds which are continuous within a rather broad quantitative range of assimilate availability. Periodic alterations in nut yield is therefore regulated by imbalances in the supply and demand of photoassimilates within a compartmental unit during the critical developmental phases of 'flowering' and 'cotyledon development'.

Assimilate Reserve Phase (ARP). Within the context of the above described 'ARP' concept, if levels of dormant season assimilate reserves are below the threshold required for the initiation of flower development in early spring (during the ARP), then male and/or female flowering will be reduced. The critical storage assimilate appears to be starch found in roots (Wood 1989, Smith and Waugh 1938). Such levels correlated well with production when studied for several years in the field environment. While correlation can only be interpreted as circumstantial evidence, previous research has indirectly indicated that levels of dormant season starch play a critical role in regulating nut yield. It is hypothesized that starch (and probably other carbohydrates and amino acids) levels must exceed a particular minimum level (this level would likely vary with pecan cultivar and with growing environment) before the physiological processes regulating the development of staminate flowers (catkins and pollen) are fully manifested. This level is not sensed directly by the floral meristem but is done indirectly via physiological interactions associated with the level of sugars (and maybe other carbohydrates and nitrogenous substances) available for metabolic processes.

The common observance of trees exhibiting no visible pistillate flowers, but a substantial level of staminate flowers, is interpreted as evidence that staminate flower development naturally takes priority over pistillate (female) flowers; therefore the development threshold is lower for staminate flowers. This provides an adaptive advantage in the wild insomuch that a source of pollen is usually available for out-crossing with others of the species. This is further substantiated by the observed absence of wild trees producing pistillate but no staminate flowers. As the level of available dormant season assimilate reserves increases, then the numbers of staminate flowers developing the following spring also increase to a maximum. This 'maximum' obviously defines the upper limit of the action threshold. The action threshold is therefore broad and is clinal in nature. It is not a 'black and white', or 'all or nothing' response, but is rather a 'black and white' with 'infinite shades of grey' in between. The response of the compartmental units is therefore not generally an 'all or nothing' reaction. The individual floral meristems within the compartmental unit are the basic response units. There is substantial

variability among meristems in regard to the 'availability of' and their 'sensitivity to' mobilized assimilates. This 'maximum' is achieved after surpassing the level necessary to trigger the visible development of female flowers; hence trees can be found with heavy catkin crops but moderate crops of pistillate flowers. Since there appears to be an absence of observations of trees exhibiting heavy female flower crops with light to moderate catkin crops, the upper limit of the response curves for staminate and pistillate flowers must be such that the maximum pistillate flower crop is dependent upon a higher level of assimilate reserves than do staminate flowers. The nature of these two response curves is currently unknown. For example, are they linear or curvilinear, and what is the nature of their slopes?

As growers know all too well, the presence of a good crop of female flowers does not necessarily mean a good nut crop. Flowers may abort for a variety of reasons (Sparks 1986). Some abort due to external stress (cold, wind, drought, insects, disease, etc.) whereas others abort due to internal stress (such as selfing, nonpollenation, incompatible pollen parent, or due to insufficient assimilate reserves). Abortion of staminate flowers due to insufficient assimilate reserves is a common reason for crop failures in pecan. This mechanism is associated with an assimilate threshold that is only a little higher than the threshold required for the production of pistillate flowers. If dormant season assimilate reserves are sufficiently high, then trees will enter the summer with a heavy crop of developing fruit and likely produce a good nut-set.

Assimilate Production Phase (APP). This mechanism becomes operative in early summer and acts to regulate further nut development and ripening. This phase largely influences nut size, the degree of kernel filling, and possibly a portion of the fruit abortion associated with the 3rd drop. The driving factor during this period appears to be the "source to sink" relationship. If this ratio is below a certain action threshold, then nuts will fail to fill and will subsequently produce pops (Sparks 1974). However, it should be recognized that the production of pops is sometimes due more to disease factors (especially pecan anthracnose) than to alternate bearing processes. Similarly, if the ratio is too high, then kernel filling is again poor because of excessive partitioning of assimilates to prolific second-cycle vegetative growth. Under this situation the sink strength of the kernel is not enough to successfully compete with excessive new shoot growth (Wood 1988). This mechanism is pronounced on especially vigorous trees possessing a high leaf to fruit ratio and is therefore most commonly exhibited by young trees.

As a tree ages physiologically, the average number of nuts set per flower cluster generally diminishes. This is largely due to a shift in the source:sink ratio. This means that if a grafted tree is only marginally able to fill its nuts when young (8-12 years-old), then the clone will be a progressively stronger alternate bearer as it ages and will subsequently produce poorly filled kernels.

A grower's challenge is largely two-fold. First, he or she should manage an orchard so as to stabilize orchard productivity and nut quality at a moderately high level. Secondly, production from individual trees should also be at a moderate to high level from year to year. Both objectives are interrelated insomuch that good cultural and pest management practices reduce the degree of alternate bearing.

A second regulatory level obviously encompasses either hormone-like factors or the receptors of these factors; however, little or no objective information is available (that has been derived from pecan) regarding their roles. Extrapolations from other crops (such as apple and pears) suggests that these hormone-like factors are the primary regulators of alternate bearing. They could also exert similar roles in pecan, however preliminary observations have not provided convincing evidence for this. For example, biweekly removal of fruit from major limbs throughout the growing season (June - Oct.) resulted in no differences in return bloom the following year. Also, the biweekly application of GA_3 or GA_{4+7} to major limbs did not influencereturn bloom. This suggests to the author that the hormone mechanism theorized in apple may not be operating in pecan. Alternatively, these preliminary studies on pecan might have given different results if whole trees were defruited or sprayed with gibberellins. These possibilities certainly need to be investigated.

Management Strategies

Alternate bearing at the orchard level is commonly observed when tree yield cycles have been synchronized by an environmental factor. Stress factors such as drought, winter cold, spring freezes, severe diseases, sooty mold, severe black or yellow aphids (or any arthropod that substantially reduces leaf area, and/or leaf

efficiency, and/or leaf retention or increases fruit drop), excessive wind or hail, zinc or other elemental deficiencies, etc. act to directly or indirectly reduce assimilate reserves and leads to an imbalance in the "source:sink" ratio. This disruption echoes in the form of a pronounced undulation in orchard production for several seasons into the future (Sparks 1974).

The ability of orchards to recover from severe alternate bearing cycles relates to the scion cultivars, or genetic types, being cultivated (and also to the rootstock). Some cultivars are able to recover (Desirable, Stuart, Sumner) much sooner than others (Success, Moore). Such cultivars are generally those with less fruiting stress because the number of 'set' nuts per cluster is lower. Yield cycling patterns of cultivars which set more than about 2-3 average size nuts (about 50/lb) per fruiting cluster are especially sensitive to environmental stresses and respond by exhibiting a substantial degree of alternate bearing (frequently approximating biennial bearing). Such cultivars are difficult to manage for stable production and quality, even in the most desirable environments. A few examples of these overbearing cultivars include Success, Moore, Mohawk, Chickasaw, Shoshoni, Cherokee, Mahan, Cheyenne, and Van Deman. Cultivars which naturally abort, or thin their flowers to physiologically manageable levels, exhibit bearing patterns that are much less responsive to environmental stresses. These cultivars are therefore more likely to be of greater economic value (such as 'Desirable', 'Sumner' and 'Stuart').

In addition to selecting the right cultivar, the cultural practices that are most likely to act to moderate alternate bearing by individual trees are: 1) maintaining good tree nutrition (especially, N, P, K, and Zn); 2) establishing trees on deep and well-drained soils; 3) providing the tree with sufficient water (requiring supplemental irrigation:; 4) maintaining minimal loss of assimilate production by leaves or a loss of developing fruit as a result of disease, mite, or insect pests; 5) thinning of excessive fruit loads (will probably involve the utilization of a mechanical shaker); and 6) configuring orchards to maximize sunlight utilization during the autumn (late August - mid October).

The primary step in reducing the significance of the alternate bearing problem is to utilize the best available scion and rootstock materials. While the rootstocks ability to absorb nutrients, to accumulate assimilates and to mobilize assimilates is of obvious importance, little is known concerning which genotypes are most suitable. Preferred scion cultivars are those which self-thin their fruit sufficiently to neutralize the impact of stress factors on next year's flower development. Growers should be careful, for the time being, about planting cultivars that are both precocious and prolific since these are likely to overproduce by the time the tree is 12 to 15-years-old, resulting in severe alternate bearing problems and the orchard being lost as a productive unit. Breeding efforts will likely be able to eventually separate these two characteristics. Major scion traits that impact alternate bearing are 1) size of fruit cluster; 2) size of fruit; 3) degree and timing of self thinning; 4) tree architecture; 5) photosynthetic efficiency; 6) ability to store and mobilize assimilates; 7) disease and pest resistance; 8) and length of leaf retention. These factors should be taken into consideration in efforts to develop new scion cultivars.

The fact that border trees of orchards are more productive than interior trees should help the orchard manager recognize that sunlight is also a major factor influencing alternate bearing. Its impact has probably been underestimated and merits intense investigation. The quantitative and qualitative aspects of solar irradiation obviously play a major role in tree productivity; however, a dearth of studies on light related problems has resulted in a failure to provide accurate guidelines for pecan. Studies by both Hunter (1963) and Wood and Joyner (1990) have indicated that a deficiency of sunlight during the kernel filling phase results with poor yield. This is especially significant insomuch that yield is the ultimate indicator of alternate bearing. Recent research has shown that, for all practical purposes, a pecan tree cannot get too much sunlight (independent unpublished observations by both Wood and Anderson). Since there is currently no objectively based model available to determine pecan orchard configuration (spacing and tree shape), much work needs to be done in this area. Sunlight interception is especially important to orchards growing in the southeastern U.S. because of the natural abundance of "frontal" and "convectional" clouds during the growing season. These clouds block about 30-40% of the possible sunlight from reaching the orchards (Wood and Joyner 1990). Trees should therefore be managed to make the best use of available sunlight. One major consideration is orchard crowding. Trees should be pruned or thinned so as to minimize unnecessary shading; however, the optimum degree is unknown and will be difficult to determine.

Work in other crops has revealed that there is generally better sunlight interception if the crop is grown with rows extending "North-South" rather that "East-West" (Westwood 1988). This 'may' or 'may not' be true for pecan. It is possible that an E-W orientation will be best for pecan because sunlight interception needs to be greatest in the 'APP' phase, which is operative in late summer and early fall. N-S or E-W row orientation obviously requires that within row spacings be smaller than between row spacings. This may not be wise in pecan since the species has little ability to tolerate the shade conditions that would likely be experienced within rows (Wood and Payne 1991). This suggests that a square, quincunx or hexaugular spacing might be better than a rectangular spacing, especially if light utilization is to be optimized within the context of over-shading. Additionally the "latitude" at which a crop is grown impacts the optimal orchard spacing due to the change in the sun's position in the sky. The importance of the North-South row effect generally increases as latitude increases. Or rather, the farther North pecan is cultivated, the more the impact of non 'North-South' rows on reducing sunlight utilization during midseason. Also, the distance between rows should be greater in the North than in the South due to 'cross-row' shading. This is due to changes in solar altitude with latitude.

A big unknown in pecan cultivation relates to that of optimal spacial arrangement. Trees currently are planted at a variety of spacings and orientations with only indirect information being used to justify such decisions. For example, 'between' and 'within' row spacings ranging from 30 to 60+ feet are typically utilized in commercial orchards. If pecan trees are planted on a square, should trees be oriented N-S or be shifted 45° to a NE-SW orientation? While these are but a few of the questions that need to be resolved if alternate bearing is to be minimized, it should be clear that obviously crowded orchards (those exhibiting death of lower limbs) mean that the alternate bearing effect will become increasingly pronounced as the tree ages.

Another unknown relates to just how much shading should be tolerated before an orchard is thinned? Opinions vary from about 50% shade (at solar noon on June 22nd) to about 80% shade. Unfortunately, there appears to be no objectively derived data that answers this question for pecan. The answer is probably dependent upon canopy shape and latitude; hence, varying with orchard location and cultivar. The derivation of this answer will not likely be soloed via total objectively because of the time required to test the hypothesis would be impractical under the contemporary research environment.

The above brief discussion of alternate bearing will help those involved in pecan husbandry to better deal with this important biological problem. In the short-term, the best strategy for the orchard manager appears to be that of incorporating cultural and pest management practices which keep trees growing vigorously (but this can be over-done), especially when they begin to chronologically age (10+ years-old). This helps to keep the leaf area to fruit ratio in balance, therefore producing relatively consistent crops of good quality. This task becomes increasingly formidable as the tree matures because of an ever increasing respiratory load and increasing number of fruiting points. The alternate bearing effect is far from being eliminated; however, the perceptive orchard manager should be able to minimize its impact by keeping in mind the nature of the problem. The "root" of the alternate bearing problem obviously lies in the genetic makeup of the scions and the rootstock. The interaction of these genotypes with the environment and with each other is the manifestation of the basic factors. Until the genetics can be altered, the most direct alternate approaches would appear to focus on regulating overproduction. This is likely most easily obtainable by mechanical thinning and the avoidance of cultivars with excessively large nuts (>45/lb) and to avoid clusters with several nuts set per cluster (>3/cluster). These strategies may simply be more "chopping", but at least the chopping is on the "trunk" rather than on the "leaves".

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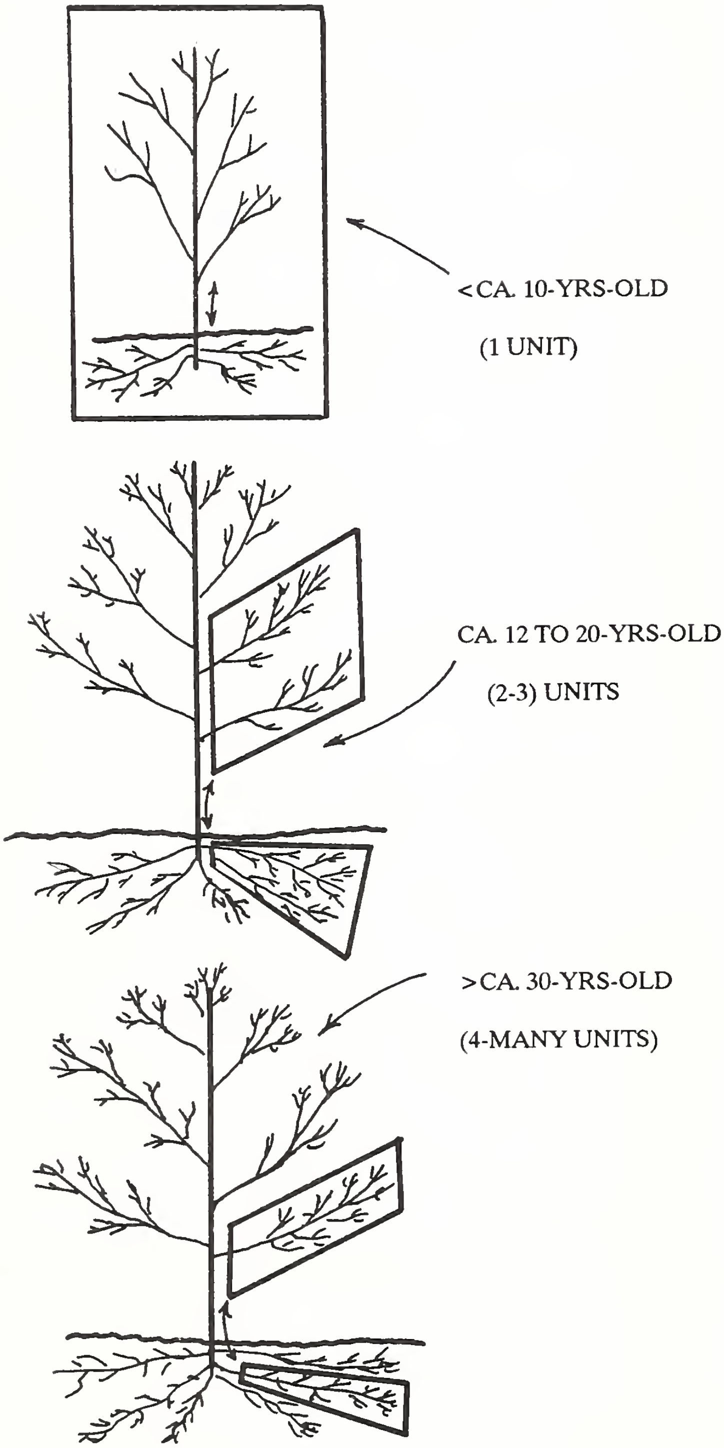
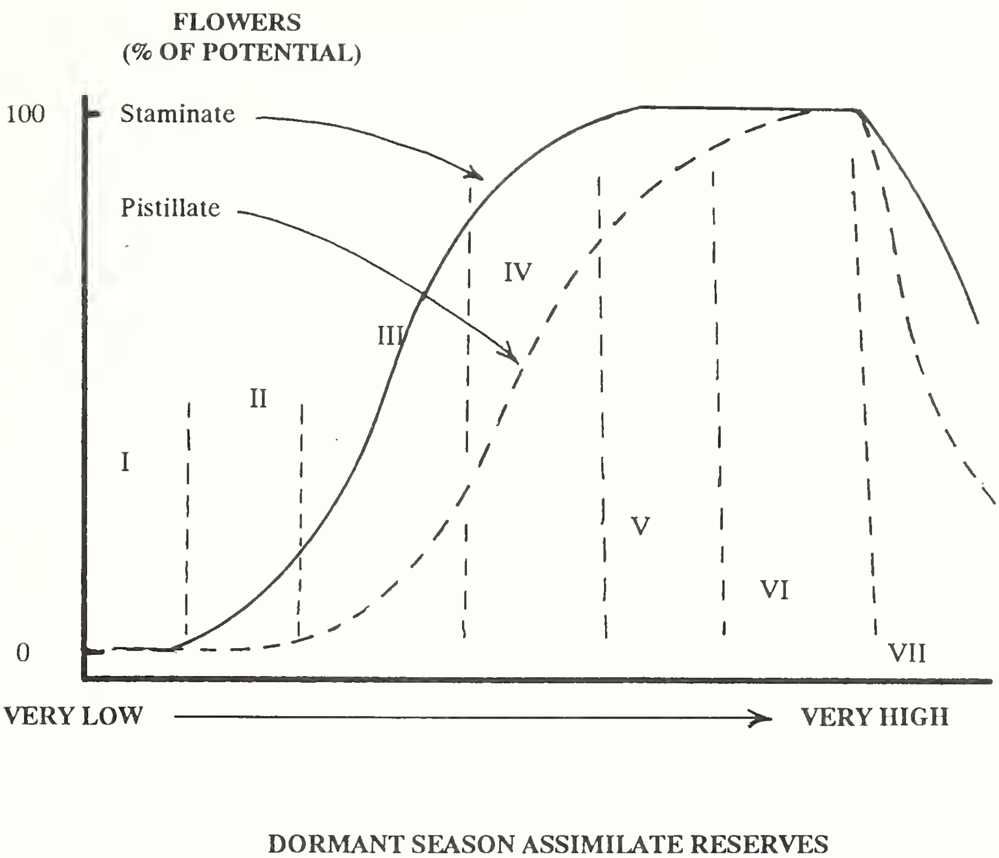


Figure 1. Changes in compartmentalization of pecan trees as they become larger.

"ASSIMILATE RESERVE PHASE"

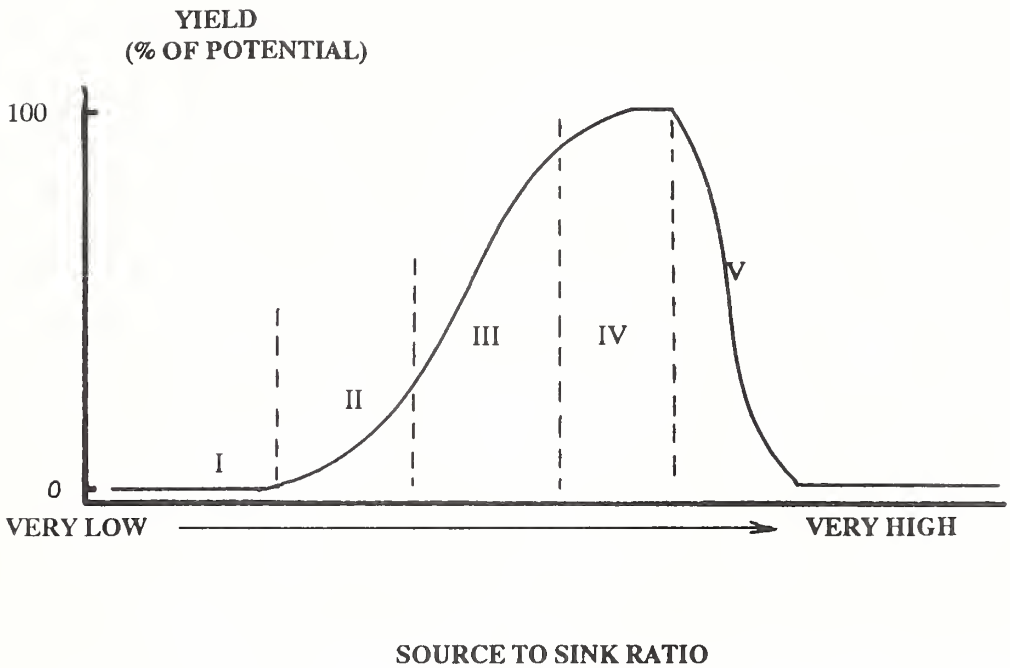


FLOWERING RESPONSE

Subphases	Staminate	Pistillate	Nut-set
I	-	-	-
II	+	-	-
III	++	+	-
IV	+++	++	+
V	++++	+++	++
VI	++++	++++	+++
VII	+++	++	+

Figure 2. **Characterization of the 'Assimilate Reserve Phase' of alternate bearing.**

"ASSIMILATE PRODUCTION PHASE"



YIELD RESPONSE

Subphases	Volume	Number	Kernel - %
I	+	+	-
II	++	++	+
III	+++	++	++
IV	+++	++	+++
V	+++	++	-

Figure 3. Characterization of the 'Assimilate Production Phase' of alternate bearing.

PRODUCTION RAPPORTEUR

Darrell Sparks[1]

Both short-term and long-term tactics dealing with pecan production problems have been presented. Individualized approaches and opinions related to improving the status of the pecan industry surfaced during the course of this program. Highlights emerging from the presentations included: 1) methods for conducting research; 2) cultivar selection and improvement; 3) pest management schemes; and 4) optimizing water availability and maximizing sunlight reception by the tree.

METHODS FOR CONDUCTING RESEARCH

Procedures employed by pecan scientists to solve production problems are as varied as the size of nuts produced by pecan cultivars. Regardless, three criteria should be met before experimentation is initiated on a production problem. The factors responsible for the problem should be systematically itemized, scientists from each discipline should evaluate the problem, and existing information should be thoroughly analyzed before proceeding with actual experimentation.

The approach to solving pecan production problems described by W. Reid and R.D. Eikenbary in "Developing Low-input Management Strategies for Native Pecan Orchards" should be adopted by researchers and extension personnel as a model for designing systems to improve pecan culture. Reid and Eikenbary first analyzed the source of the major costs incurred in the total management program for pecan and then directed extension and research efforts towards reducing and/or minimizing each of these costs. Reid and Eikenbary's total approach should be extended to all pecan growing regions.

Currently, pecan research is fragmented by specialty as evident in most of the papers presented in this conference. The role of clover as a cover crop in the orchard is an example of a research area which would benefit from a team effort. The function of clover in a pecan orchard has different connotations to scientists with different specialties. Clover is regarded by the horticulturist as an alternate source of nitrogen, by the irrigation specialist as draining the water supply, by the entomologist as a host for beneficial insects, by the pathologist as creating humidity conditions conductive for scab infection, by the food scientist as decreasing kernel quality by shuttling nutrients away from tree growth, and to the economist as an additional cost in orchard maintenance. Formulation of an integrated research program for clover usage, as well as other production problems, would be an excellent charge for the next pecan workshop.

Pecan personnel, and especially horticulturists, often fail to read the literature and keep abreast of industry needs. Many of the fundamental horticultural and pest control principles in pecan were established 30 to 60 years ago. Even though much of this information was published in grower journals, the data are valid and the results should be studied prior to initiating a research project and cited in papers generated by the research. The net result is that we as pecan horticulturists often rediscover the wheel as was evident in some of the papers presented at this conference. More innovative research, such as the rootstock work of L.J. Grauke and the pollen fertilization work of R.D. Marquard, is needed.

Lack of keeping abreast of industry innovations has resulted in horticulturists and other pecan scientists publishing results on culture practices the grower has been employing for years. Classical examples of innovations developed either partially or totally by growers and industry personnel, but mimicked by researchers include mechanical harvesting, the Quantz cracker, and early nut harvest. In addition, the growers have pioneered irrigation and other requirements for maximizing tree productivity such as water requirement, tree spacing, pruning, and thinning. Horticulturists, and other scientists, can become the innovators provided they take the time to learn the problems and needs of the industry. A classic example of a scientist who took this approach is W.R. Forbus. His work on steam treatment of nuts has revolutionized the pecan processing industry. Another example that may become classical is mechanical fruit thinning innovation of M.W. Smith and J.C. Gallot.

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CULTIVAR SELECTION AND IMPROVEMENT

Emphasized throughout this conference was the precept that no totally suitable cultivar exists in spite of close to one hundred years of breeding and testing. In addition, many orchards consist of cultivars that are marginal and submarginal in production. There are at least two primary factors responsible for this sad state of affairs. One is that breeders and other originators of cultivars have not had an adequate understanding as to the combination of characteristics required in a cultivar to maximize profits. Another is that cultivars have not been adequately tested prior to release. During this conference, a cultivar with a high kernel percentage was repeatedly cited as high priority with 'Western Schley' being used as the standard for comparison. However, by industry standards, 'Western Schley' is definitely not a high quality nut regardless of its high kernel percentage. In cultivar selection, emphasis should be given to the market value of the nut or the monetary return per acre. Pecan personnel should confer and draw up the characteristics needed in a cultivar. Industry representatives, both growers and processors, should be included in this discussion.

Historically pecan cultivars testing has been more or less a sham. Funding has been inadequate and sometimes analyses have been conducted by disinterested or unqualified people. In addition, trees grown under submarginal cultural practices and staggered tree plantings within a test over time invalidate some conclusions. Another major problem in cultivar testing is that sample size is almost always too small with some plantings actually being cultivar collections rather than tests. These problems were evident in presentations in this workshop. Consequently, factual data on pecan cultivars are minimal regardless of whether the cultivars are new or old. Standard guidelines should be established for cultivar testing. Testing should be restricted to interested and qualified personnel and consist of a team effort. The minimum disciplines represented by the team should be horticulture, entomology, and pathology.

I.E. Yates suggest in "Tissue Culture of Pecan" that genetic variation in nature has more immediate potential than tissue culture for selecting trees with improved production characteristics. For example, in the southeastern United States, there are individual seedling that are noted for outstanding characteristics, such as early nut ripening, and/or disease and insect resistance. These seedlings should be systematically surveyed for potential cultivars and/or genetic material for breeding. However, as yet, there appears to be little interest in this potential.

PEST MANAGEMENT SCHEMES

The threat of increased pesticide restrictions by the Environmental Protection Agency and the major cost of pesticides in orchard management budgets heightens need for immediate development of practical pest management schemes. Extensive discussion centered around biological control. Biological control does have potential in pest management strategies and requires more research. However, biological control is presently feasible only with aphids. Pressures from other insects, such as stink bug and shuckworm, make insecticide usage a requirement for nut production. Similarly, breeding for scab resistance may be productive in the long-term. Presently, fungicides are the only means of scab control. Thus, the need for new and preservation of existing pesticides remain high priority. Except for Mizell's paper, the pesticide dilemma facing the pecan industry was not directed addressed.

The paper by R. F. Mizell, "Pesticides and Beneficial Insects: Application of Current Knowledge and Future Needs" describes the effect of pesticides on beneficial, as well as pest insects. The lack of knowledge on the negative impact pesticides have on beneficial insects is immense. Mizell's work was the only paper presented during the conference that directly addressed the problem of controlling pest insects and maintaining beneficial insects. This is an area that must be treated to more investigation.

OPTIMIZING WATER AVAILABILITY AND SUNLIGHT RECEPTION

The importance of irrigation in pecan production was stressed in the paper by R.E. Weber, "Orchard Management". Of concern is the apparent inadequateness of many drip irrigation systems. More information is needed to maximize the benefits from drip systems either by improvements in existing systems and/or scheduling the limited water for maximum economical return. Horticultural extension personnel need to fully educate the grower and irrigation companies on the water requirements of pecan so that future installation of inadequate drip systems will be minimized.

The importance of maximizing sunlight reception in pecan orchards was also emphasized by Weber. Weber's strategy of progressive limb and tree

removal and H.A. Hinrichs' data on the relationship of nut yield to the percentage of the orchard floor with sunlight are significant contributions. If their information were used more extensive by the industry, both yield and kernel quality would be increased. However, more work is needed to pinpoint the critical sunlight exposure and to determine the best cultural approach to maintain critical exposure. More research is needed to determine the photosynthetic characteristics of pecan trees as presented by P.C. Andrews.

In summary, this pecan workshop provided a forum for interaction among pecan personnel from all disciplines. The workshop also allowed, for the first time, a rewarding opportunity for interaction with key industry personnel. These interactions will no doubt allow each of us to become better students of pecan which, in turn, will benefit the industry. Now the challenge is to put this interaction into practical applications, instead of intellectual discussions. Pecan research and extension would render a valuable service to the grower if scientists from all disciplines joined together to formulate a basic cultural program stressing maximum production at minimum cost. Formulation of such an integrated culture program would be an excellent task for the next pecan workshop, even though the effort may have the same fate as the Tower of Babylon. In addition, the next conference can better serve the pecan industry if the major problems of the industry are systematical identified followed by a proposed solution or, if no solution, research priorities are established to solve the problems.

POSTHARVEST QUALITY

S. J. Kays[1]

With harvest, pecans begin to undergo a series of chemical alterations, the majority of which are irreversible and largely detrimental to quality. The general physical and chemical condition of the nuts at harvest and their subsequent rate of change are dependent upon a number of pre- and postharvest factors. The following report will focus upon the components of quality in the pecan and the critical factors that result in the loss of quality.

Harvested pecans represent live, metabolically active organs with cells that respire (i.e., utilize oxygen and give off carbon dioxide), synthesize a cross-section of chemical compounds and carry out routine maintenance reactions. Pre- and postharvest factors that alter the rate of these reactions in an undesirable manner have a detrimental effect on quality. The general condition of the nut at any point in the production-harvest-storage-marketing chain is the collective effect of its genetic makeup, the environmental conditions to which it has already been exposed and the conditions to which it is currently being exposed. Understanding the importance and interrelationship between these factors allows us to better minimize undesirable changes in quality.

COMPOSITION

Pecan quality and changes in quality after harvest are strongly modulated by the basic chemical composition of the kernels.

The chief constituents of pecans are lipids (primarily oils), proteins, carbohydrates, and a cross-section of quantitatively minor components (Table 1). In some instances, alterations in specific minor components have a significant effect on the overall quality of the nut.

A) Lipids. Lipids are the primary constituents of pecans (Table 1) and changes in the lipid fraction are responsible for the rancid flavor that occurs when the nuts are improperly handled. The lipid content varies widely due to cultivar (Rudolph 1971, Woodroof and Heaton 1961, French 1962, Odell et al. 1971, Senter and Horvat 1976, 1978) (Table 2), year (Odell et al. 1971) (Table 3), location (Odell et al. 1971), agronomic practices (e.g., nitrogen fertilization, irrigation), soil type, climate, level of nut set, and maturity (Heaton et al. 1977).

Pecans contain primarily neutral lipids that have a sufficiently high level of unsaturation to render them liquid at room temperature. Of the lipids present, 97.4% (mean of six lines) were triacylglycerols, 0.3% α, α' -diacylglycerols, 0.87%, α, β-diacylglycerols, 0.72% monoacylglycerols, 0.22% sterol and 0.52% complex lipids (Senter and Horvat 1976). Hence, predominating are triacylglycerols, comprised of three fatty acids (acyl groups), (Figure 1).

The stability of lipids is closely related to the degree of unsaturation of the fatty acids present; the higher the number of double bonds, the greater the potential for reaction with oxygen and the formation of rancidity. As a consequence, considerable research has been directed toward analysis of the fatty acids present in the pecan. Oleic (single double bond) and linoleic (two double bonds) acid concentrations have been monitored in a large number of cultivars (Woodroof and Heaton 1961, French 1962, Odell et al. 1971, Senter and Horvat 1976). Oleic acid was found to range from 51 to 77% of the fatty acids present. The most complete analysis to date identified twenty-three fatty acids (Table 4), nine saturated and fourteen unsaturated. Unsaturated fatty acids comprised approximately 88.5% of the total and ranged in degree of unsaturation from one double bond (e.g., oleic) to three in linolenic. The composition of fatty acids is known to vary widely due to cultivar (Table 5) and year of production (Table 6) (Odell et al. 1971). Oleic acid ranged from 78.1% in selection H68L1 to 53.4% in the cultivar 'Hayes' and linoleic acid from 37.4% in 'Hayes' to 14.0% in 68L1 (Odell et al. 1971). A negative linear relationship was found between the percentage of linoleic acid and the keeping time of pecan oil (Figure 2) (Rudolph 1971). Conversely, a positive linear relationship existed between the percentage of oleic acid and keeping time (Figure 3). As the percentage of oleic acid in the lipid fraction decreases in pecans there was a corresponding increase in linoleic acid

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(Figure 4) (Rudolph 1971). This is due to conversion of stearic (18:0) to oleic (18:1) and then linoleic acid (18:2) *via* a sequential insertion of double bonds (Figure 1).

Oxidation of pecan oils involves an induction period during which time peroxides are formed. The induction period is followed by an increase in low molecular weight aldehydes. An additional component of the lipid fraction are the tocopherols that act as natural antioxidants, i.e., they are thought to protect the fatty acids from attack by oxygen (Figure 1). A positive relationship has been reported between the tocopherol concentration and the stability of pecan oils (Pyriadi 1967). Likewise, coating pecans with tocopherol decreased the rate of development of rancidity (Godkin et al. 1951).

Although four chemical forms (α, β, γ, and δ) of tocopherol are present (Yeo et al. 1990), γ-tocopherol (Figure 1), makes up over 95% of the total (Lambertsen 1962). This is in contrast to most nuts in which α-tocopherol predominates when oleic is the primary fatty acid present. The concentration of tocopherols in the pecan varies significantly with cultivar (Table 7) (Rudolph 1971). While the actual concentration of tocopherol present did not appear to correlate with the length of time required for pecan oils to become rancid (keeping time), addition of γ-tocopherol to extracted oils prolonged longevity (Odell et al. 1971).

B) Carbohydrates. Carbohydrates made up a much smaller percentage of the kernels than lipids (Table 1). Total carbohydrates typically represent 13 to 15% of the edible portion of the nut. Cell wall carbohydrates - cellulose (1.76%) and hemicellulose (4.09%) - represent a dominant group as well as several free sugars, e.g., sucrose (1.18%) inverted sugars (2.88%), araban (1.95%) and methylpentosans (0.22%). Starch was absent, however, small amounts of amyloid (0.59%) and tannins (0.33%) were present.

C) Protein. Pecan protein content varies among cultivars, ranging from 7.2% in the cultivar 'Jack Ballard' to 16.9% in the selection 504 (Table 2) (Odell et al. 1971). The percentage of protein tends to vary with production year. For example, the cultivar 'Success' ranged from 13.4 to 9.5% protein between two consecutive years.

Hydrolysis of the protein fraction yields the constituent amino acids (Table 8). There is significant variation between cultivars in their amino acid composition (Merideth 1974), however, location differences were not significant. The cultivar 'Stuart' had an essential amino acid , total of 3507 $mg.100g^{-1}$ dwt and a nonessential amino acid total of 5827 $mg.100g^{-1}$ dwt. The amino acid concentration of the pecan is not particularly high when compared with other food products, i.e., roughly comparable to cereal grains (FAO 1970). Comparison of the amino acid composition of the pecan with that of eggs indicated that lysine was the most limiting essential amino acid (Merideth 1974).

D) Volatile Compounds. Volatile compounds represent a critical portion of the overall flavor of the pecan. Flavor is comprised of the combined effect of taste - that which we detect with our mouth, and odor - detected by the olfactory epithelium. While we are thought to perceive primarily only four primary taste sensations (i.e., sweet, sour, salty, and bitter), it is possible to distinguish up to 10,000 individual aromatic compounds. The importance of the aromatic fraction is illustrated by the fact that we do not have to taste a pecan to tell if it is rancid. The characteristic off-odor of a rancid pecan is very distinctive, instantaneously triggering a rejection response signal from the brain.

Many of the volatile compounds emanating from raw pecan kernels have been identified (Table 9). These include a series of alcohols and aldehydes and one lactone (α-caprolactone) (Rudolph 1971). Pyrazines make up the backbone of the characteristic roasted pecan aroma (Table 9) (Wang and Odell 1972). They are thought to be derived *via* several possible mechanisms (i.e., the reaction of sugars and amino acids within the kernels) (Koehler and Odell 1970). Likewise, pyrazines can be obtained by heating amino-hydroxy compounds (e.g., serine, threonine, ethanolamine, glucosamine, and 4-amino-3-hydroxy-butyric acid), especially when the amino and hydroxy groups are on adjacent carbons (Wang and Odell 1973). The odor detection threshold levels have been established for a cross-section of these compounds (Koehler and Odell 1971).

E) Pigments. The pigmentation of pecan kernels is localized in the thin layer of surface cells making up the testa. Our current knowledge of the chemistry of these pigments is quite limited, although flavonoids and carotenoids are thought to predominate.

Pecan carotenoids have been separated into carotenes and mono-, di- and polyhydroxy xanthophylls (Senter 1976b). The latter of the four classes appears to predominate. No

differences were found between six cultivars for carotene and total carotenoid concentrations, however, there was significant variation in the three classes of xanthophylls (Senter 1975). While carotenoids are thought to repress oxidative rancidity of pecan oils (Pyriadi and Mason, 1968), the absence of distinct cultivar variation suggest that existing cultivar variation in oil stability is not related to carotenoid content.

Discoloration of pecan kernels with age is caused in part by the transformation of largely colorless leucocyanidin and leucodelphinidin to their pigmented oxidative derivatives - phlobaphenes and anthocyanidins (Senter 1976b). The concentration of both pigments increases with increasing duration of storage (Figure 5).

Iron associated with the surface pigment fraction of the testa is subject to changes in oxidation state which results in a pronounced alteration in color (von Wandruszka et al. 1980). The surface iron content of four cultivars ranged from 20.9 ppm ('Stuart') to 14.7 ppm ('Schley') and represented approximately 20% of the total iron in the kernel. When the nuts are exposed to ammonia vapor, the testa becomes intensely black due largely to changes in oxidation state of the surface iron atoms. The role of iron is illustrated by the enhanced coloration obtained with reduction of iron using stannous chloride[2] (Table 10) (von Wandruszka et al. 1980). The degree of lightening was negatively correlated with the surface iron content of the cultivars tested. Acidification of the surface of the kernels using a dilute phosphoric acid solution (0.25 M) followed by washing will also lighten the kernels and partially reverse ammonia induced discoloration (Kays and Wilson 1977).

F) Phenolic Compounds. Phenols are widely distributed in the plant kingdom with flavonoids making up one of the largest groups (Harborne 1973). The concentration of phenolic compounds in the kernels varies between cultivar at harvest; for example 'Stuart' had 10.7, 9 $mg.g^{-1}$ kernel and 'Schley' had only 8.3, $mg.g^{-1}$ (Senter 1976b).

[2]Due to the toxicity of stannous chloride this is not a viable commercial practice.

G) Minerals. The concentration of Cu, Fe, Co, Cr, Al, Mn, B, Zn, Mo, Sr, Ba, Na, P, K, Ca, and Mg in pecan kernels is given in Table 1 (Senter 1976). Iron concentration is known to be related to coloration (von Wandruszka et al. 1980). Likewise, certain metals (e.g., Cu, Fe, Co, and Cr) have been shown to accelerate the oxidation of fatty acids (Lundberg 1962). Significant differences have been found between cultivars for Cu, Fe, Cr, Mn, B, Zn, Ba, P, K, and Ca concentration (Senter 1976). Differences in the concentration of oxidation promoting metals may in part relate to cultivar variation in oil stability.

H) Vitamins. The pecan is a fair source of vitamins (Table 1), being significantly higher in certain vitamins than many of the other common nut crops. Pecans contain substantially more vitamin A than almonds, chestnuts and peanuts and have approximately 3 times the thiamine content of almonds (Leung et al. 1952).

I) Shell Components. Pecan shells comprise approximately 50% of the weight of the harvested crop. Although considerably less valuable than the kernels, the shell portion nevertheless has significant value, much of which is not yet fully exploited (Kays 1979, Kays and Odell 1978). Shells can be separated into the hard outer layer of highly lignified material and the softer interior packing tissue. The amount of each per nut varies widely with cultivar (e.g., shell weight ranged from 1.6 to 4.1 g per nut and packing tissue weight from 0.6 to 1.7 g) (Kays and Payne 1982). Shells of the cultivar 'Stuart' contained 38% lignin, 15% cellulose, 18% hemicellulose, 24% pentosans, 1.3% ash, 1.6% protein, and 0.5% pectic substances (Avants and Pressey 1972). Extractable phenolics which can be used for making bakelite plastics, thermal insulation, laminated materials, particle or composition board and other products (Kays and Odell 1978) varied from 0.06% to 1.5% in the outer shell and 20.2 to 52.6% in the packing tissue (Kays and Payne 1982).

Distinct changes in quality occur in pecan shells with time after harvest. Likewise, if left in the field under high moisture conditions the phenolic components can leach from the shells of intact nuts causing discoloration of the kernels (Woodroof and Heaton 1961, Heaton et al. 1975).

COMPONENTS OF QUALITY

Like most aesthetic traits, what we perceive as quality is in the eye of the beholder. Thus what is considered as critical quality components

depends upon whom is evaluating the product and its intended use. While the primary components of quality can be defined, whether they are utilized and what weight is placed on each component varies considerably.

A) Color. The color of the testa is a primary quality attribute with light colored kernels being preferred. The majority of color development during maturation on the tree occurs after the onset of dehiscence (Kays and Wilson 1977a). This is followed by a progressive synthesis of pigments after harvest (Senter 1976).

Use of color as a measure of quality is based largely on a characteristic darkening of the surface color as the kernels age (Kays and Wilson 1978). With aging there is also an increase in lipid rancidity (Odell et al. 1971) and a decline in the nuts characteristic aroma, flavor and textural properties. During discoloration, the surface is transformed from a light golden color to a dark red-brown (Kays 1979). Generally, postharvest changes in color tend to coincide with decreasing quality; however, they do not necessarily change parallel to each other, e.g., the rate of color change varies between cultivars (Figure 6). In some cases, color is not an accurate indicator of flavor quality. For example, at optimum harvest there is considerable variability in the color between pecan cultivars (Figure 6) (Kays and Wilson 1978). With dark colored cultivars, other quality attributes are not necessarily low in proportion to color.

Postharvest color alterations can be separated into two general classes: those that represent normal pigment alterations with aging and abnormal or atypical color changes (Kays 1982). The synthesis of phlobaphene and anthocyanidin (Senter 1978) is an example of the former while discoloration due to exposure to ammonia (Kays 1979, Medlock 1931, Medlock 1933, Rose 1939) is an example of the latter.

B) Flavor. Fresh pecans have a distinctive, pleasing aroma and taste and are often consumed without roasting. Collectively, aroma and taste comprise flavor and flavor represents the single most important quality attribute utilized by consumers. Due to the manner in which the nuts are sold (i.e., sealed packages) flavor assessment is normally only made after purchase, thus flavor influences use and subsequent purchases. Flavor is generally not used as a measure of quality at the wholesale or retail levels, the exception would be when there is a distinctive off-flavor. The reason for this is that flavor is currently measured only subjectively due to our general lack of understanding of pecan flavor chemistry. As a consequence, there are no objective measures of flavor quality, hence the absence of standards and grades.

Considerably more progress has been made in studying the aromatic properties of pecans than taste. The characteristic volatile flavor components are the first quality attributes of the kernels to be lost during the general decline in quality after harvest (Woodroof 1979). The major volatile compounds given off by raw pecans have been identified. These include four low molecular weight alcohols, five low molecular weight aldehydes and a lactone (Table 9) (Rudolph 1971). It is thought that their origin may occur *via* the oxidation of unsaturated fatty acids which are found in significant levels in the nuts. Which of these volatile compounds are of critical importance in the aroma and their relative concentrations is not presently known.

In roasted pecans, nineteen carbonyls, pyridine and eight pyrazines, seven acids, five alcohols, and one lactone have been identified as volatiles emanating from the kernels (Table 9) (Wang and Odell 1972). The alkyl-pyrazines appear to provide the backbone of the roasted nut character, however, the carbonyl and basic compounds are also important. As with raw pecan, the precise compounds and their relative proportions are not known. The characteristic aroma of neither raw nor roasted nuts has been synthetically reproduced.

The oil content of the kernels varies widely and is closely associated with flavor (Woodroof and Heaton 1961). High oil content nuts are preferred over those that are low in lipids. The relationship between fatty acid composition and flavor has not yet been explored.

Pecan flavor is known to vary between cultivars (Brison 1945) and storage conditions have a pronounced affect. Our understanding of the factors affecting flavor has centered almost exclusively on parameters that result in off-flavors. How long the nuts take to become rancid, the "rancid induction period," was studied over 50 years ago (Knight 1938). The greater the temperature and/or the higher the linoleic acid concentration (Figure 2), the faster the nuts become rancid. Pecans also readily absorb lipophilic gases from the atmosphere surrounding the nuts. When the gas atmosphere contains off-odors from any source (e.g., ammonia, paint,

asphalt, fruits, and vegetables such as onions), these are readily absorbed and result in reduced flavor quality.

C) Kernel Fill. Kernel fill is also an important component of quality. Nuts that are poorly filled do not possess the visual attractiveness, flavor quality or textural properties of high quality nuts. A critical period for nut fill is in the latter stages of development, the precise date varying with location, cultivar and production year. For the cultivar 'Moore' grown in southern Georgia, 63% of the kernel dry weight and 64% of the oil was accrued between August 25 and September 15 (Hammer and Hunter 1946).

D) Condition. The general physical condition of the kernels modulates our assessment of their overall quality. The absence of insects and/or insect damage, freedom from diseases and the absence of breakage and foreign material are critical. Likewise, the size of the kernels and their textural properties are important. Nuts that are inadequately dried or are stored in high relative humidity environments in which they absorb moisture have inferior textural properties. As the moisture content rises above 4.0%, the kernels become progressively more spongy and moist. Relatively small increases in water content can have a pronounced affect on texture. Conversely, when stored at exceedingly low relative humidities and/or when overly dried the kernels become excessively crisp and brittle. This also decreases their textural quality and greatly increases the chances for breakage during handling.

CRITERIA USED BY THE INDUSTRY TO ASSESS QUALITY

Quality assessment of agricultural products can be made by monitoring each individual product unit or each unit in a subsample removed from the entire volume. As the size of each individual product unit decreases and the number of units per given volume increases, it often becomes impossible to monitor each unit within a reasonable time frame, hence the need for subsamples. Essential requisites for quality assessment of individual units are that the measurements can be made: 1) rapidly; 2) accurately; and 3) nondestructively. Because of this, measurement of physical attributes such as size or color that lend themselves to rapid mechanical or electronic sorting, predominate over chemical or other types of analysis.

Hubbard (1990), found in a survey of growers, accumulators, shellers and large volume buyers that each had a different understanding of what constituted the critical components of quality. Growers felt that accumulators and shellers ascertained quality based largely on the percentage shell out. Shellers, however, listed color as the most important single parameter, followed by kernel size. Large volume buyers often had distinctly different quality criteria which were based upon their specific needs. For example, kernel size was the most important single parameter listed by the gift-pack trade while retail grocers listed color as most important. Retail consumers generally prefer light color kernels over dark (Resurreccion and Heaton 1987). Thus what are considered as critical quality attributes are, to a large extent, dependent upon whom in the production-storage-marketing chain defines quality.

The shelling industry relies largely upon kernel color and size to assess quality; both, however, have inherent deficiencies. The use of color is based in part upon the assumption that as the kernels deteriorate, there is generally a corresponding darkening of the surface pigmentation. The primary weakness of this assumption is that color and other quality attributes do not necessarily change in parallel.

For example, dark kernels may be of excellent conversely light kernels may be of low quality. This is illustrated by the pronounced range in color between cultivars at their point of optimum quality (Figure 6). Likewise, 'Farley' kernels are relatively dark compared to 'Mahan', but substantially better in flavor.

Pecan kernels are sorted by color using automated electronic equipment into the following grades.

(a) "Light" the kernel is mostly golden color or lighter, with not more than 25% of the surface darker than golden, and none of the surface darker than medium brown.

(b) "Light amber" the kernel has more than 25% of its surface light brown, but not more than 25% of the surface darker than light brown and none of the surface darker than medium brown.

(c) "Amber" the kernel has more than 25% of the surface medium brown, but not more than 25% of the surface darker than medium brown, and none of the surface darker than dark brown (very dark-brown or blackish-brown discoloration).

(d) "Dark amber" the kernel has more than 25% of the surface medium brown, but not more than 25% of the surface darker than dark brown (very dark-brown or blackish-brown discoloration) (USDA 1969).

Pecan pieces that are considered excessively dark are occasionally chopped to a smaller size to enhance their overall lightness. While the actual color of the pigmented surface remains the same, its percentage of the surface area exposed declines in relation to the cream colored interior of the nut. Hence, collectively the smaller pieces appear lighter. In some cases electronic sorters are also used to remove unacceptably dark pieces.

Kernel size is also an arbitrary measure of quality, largely dictated by economics and the eventual use of the nut. As kernel size increases, handling costs (harvest, shelling, grading) decline. Hence, there is no scientific reason to assume small kernels are inferior in quality to large kernels unless size is an essential requirement. When graded for size, the kernels are first separated into intact halves and pieces (kernels with one-eight or more of their volume missing). Both intact halves (Table 11) and pieces (Table 12) are separated into size classes.

Both color and size are used as measures of quality largely because of their ease of measurement. Of the two, color separation more closely correlates to the actual overall quality of the nuts. Secondary quality factors which influence sales include: 1) degree of filling of the kernels; 2) freedom from damage; 3) freedom from foreign material; and 4) cultivar.

PREHARVEST FACTORS AFFECTING POSTHARVEST QUALITY

A) **Cultivar.** Cultivar has a pronounced influence on nut quality at harvest, the postharvest stability of certain quality attributes and market price. Individual cultivars are known to vary widely in lipid content (Table 2), composition (Table 5), and stability (Figures 2 and 3), flavor (Brison 1945), color (Amling et al 1975, Kays and Wilson 1978), color stability (Kays and Wilson 1978), and size. As a consequence, quality considerations should be part of the over-all criteria used in cultivar selection when establishing a new grove.

B) **Location and Soil Type.** The same cultivar can vary in quality attributes with production location. Based on general quality, pecans grown in Texas were found to be superior to those grown in Mississippi (Heaton et al. 1977). Location can have a significant influence on kernel oil content (Odell et al. 1971). For example the cultivar 'Barton' grown at Brownwood, TX had an oil content that was 15.2% higher than the same cultivar grown at Goldthwaite, TX (Odell et al. 1971). Along with differences in rainfall and other climatic influences, soil type appears to influence parameters such as nut size (Skinner 1924). The best soil type varied with the cultivar grown.

C) **Irrigation and Fertilization.** Agronomic factors during production have been shown to influence quality. These include cultural practices such as irrigation, fertilization and the insect and disease spray program utilized (discussed separately). Irrigation has a significant effect on nut size (Dutcher et al. 1984) and the percent kernel (Stein et al. 1989). Adequate irrigation has been shown to increase nut size 15 to 17% over non-irrigated controls (Dutcher et al. 1984). Additional benefits include a reduced number of stick tight - fruit in which the shuck does not separate normally from the nut during dehiscence. High nitrogen fertilization does not appear to have a pronounced effect on quality, but does result in a slight decline in kernel oil content (e.g., 3-4%) (Heaton et al. 1977). Nuts from medium and high nitrogen plots had slightly lower textural and flavor quality.

D) **Fruit Load.** The number of nuts per unit leaf area on a tree can effect the eventual quality of the crop at harvest. Trees with high nut loads often have smaller nuts with lower oil contents (Heaton et al. 1977). In addition, during prolific years there is an increase in lipid iodine values and an increase in unsaturation, hence lower stability.

E) **Insects.** Insect damage in the field can reduce product quality due to discoloration (e.g., dark spots on the kernels), reduced nut size, the presence of feeding sites on the kernels and larvae and frass in the harvested product. Damage by stink bugs such as *Leptoglossus phyllopus*, L. and *Nezara viridula*, L. causes darkly pigmented spots on the kernels at harvest (Polles et al. 1973) which are bitter in taste. The kernel coloration is atypical and the discolored area may be limited to the area directly adjacent to the point of penetration, or may include all of one or both of the cotyledons (Kays and Wilson

1976). Discoloration characteristics depend in part upon the time of infestation relative to nut development. Early in the development of the nut, puncture by stink bugs results in fruit abortion and drop. However, at later stages (e.g., early to mid-October in south Georgia) pronounced discoloration occurs (Kays and Wilson 1977a). Adequate aphid and mite control has been shown to result in larger nuts (Dutcher et al. 1984). An indirect effect of insect feeding is to provide entry sites for some nut diseases (e.g., *Ervinia* sp.) (Reilly and Tedders 1989).

F) **Diseases.** The importance of preharvest diseases on nut quality varies with the organism in question. Mildew [*Microsharera penicillata* (Wallr. : Fr.) Lev.] had a significant effect on certain nut quality attributes (Gottwald 1984). For example, when 50% of the fruit was covered by the organism, the oil, protein, and free fatty acids in the kernels declined 3.8, 7.1, and 73.1 percent, respectively. In contrast, scab did not appear to effect the oil, protein, or moisture content of pecan kernels (Bertrand and Gottwald 1984) nor did "Bunch disease" affect kernel composition (Bertrand et al. 1984).

Bacterial infection by *Envinia* sp. *via* insect feeding results in kernel discoloration (Reilly and Tedders 1989). In contrast, scab did not appear to effect the oil, protein or moisture content of the kernels (Bertrand and Gottwald 1984) nor did Bunch "disease" effect kernel composition (Bertrand et al. 1984).

Many fungi are present within the internal tissues of the nut with colonizing occurring during the period after embryo development. Over 130 species of fungi have been recovered from moldy pecans (Hanlin 1985, Hanlin 1971, Hanlin and Blanchard 1974), of which those producing mycotoxins are of the greatest interest (Lillard, et al. 1970). The most prevalent fungi in the developing pecan seeds are *Cladosporium* (13%), *Fusarium* (11%), *Penicillium* (9%), *Pestalotia* (8%), *Phoma* (7%), and *Aspergillus flavas* (7%) (Hanlin and Blanchard 1974). The presence of fungi within the nut; however, does not necessarily mean the pecans will be moldy; conditions must be right for the fungi to develop. Likewise, the presence of fungi that produce mycotoxins does not necessarily mean mycotoxins will be formed. Fungi recovered from moldy pecans in one study that are known to produce mycotoxins include *Aspergillus niger*, *A. ochraceus*, *A. wentii*, *Collelotrichum* sp., *Eurotium herbariorum* (syn. *A. glaucus*), *Fusarium avenaceum*, *Penicillium aurantiogriseum*, *Trichothecium roseum* and *Trichoderma* sp. (Bertrand and Wilson 1986). The most common organisms associated with mycotoxins in pecans are *A. flavus* and A. parasiticus; however, not all strains are capable of synthesizing aflatoxin (Koehler, et al. 1975).

Damage to the fruit (shell or shuck) can increase the incidence of pathogen invasion (Schroeder and Storey 1976, Reilly and Tedders 1989). Other field conditions that increase mold incidence, growth and mycotoxin production are high nut moisture content (i.e., 15 to 30%), high relative humidity (85% or greater) and high temperature (Hanlin 1985). Delaying harvest, especially when the nuts lay on wet soil greatly increases the incidence of moldy pecans (Bertrand and Wilson 1986). Although myclotoxins, due to their high toxicity, represent potentially a serious problem, they have not been a significant factor in pecans if proper handling techniques are practiced. Mycotoxins have been found only infrequently in pecans and when present they are generally at low levels (Doupnik and Worley 1974, Escher et al. 1974, Lillard et al. 1970, Wells and Payne 1976).

G) **Pruning.** The control of tree size is a major production concern, especially after the orchard canopy begins to close and yield declines. This problem has been approached by pruning and the use of growth inhibitors, neither of which have been overly successful from the production standpoint. Severe pruning (e.g., 75%), although not commercially realistic, can reduce nut size but did not affect the percent shell out (Amling et al. 1985). In contrast, the growth regulator paclobutrazol[3] increased nut size the first two seasons after application although yield decreased (Wood 1988).

H) **Harvest Date.** The date of harvest of pecans can have a significant effect on quality, especially color, and the importance of prompt harvest is well documented in the literature (Heaton 1974, Heaton et al. 1975, Love and Young 1970, Kays and Wilson 1977a). During wet weather, leaving the nuts in the field after dehiscence can significantly increase the kernel moisture content (e.g., from 4 to 5% up to 10% within 10 days) and

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[3] β-[(4-chlorophenyl) methyl]-α-(1,1-dimethylenthyl)-1H-1,2,4-triazole-1-ethanol).

mold development (from initially mold free nuts up to 87% infected) (Heaton et al. 1977). Harvest date has also been shown to affect kernel lipid content (Heaton et al. 1977).

The majority of color development during maturation of the nuts on the tree occurs after the onset of dehiscence (Kays and Wilson 1977a). During shuck split, the oxygen concentration within the nut changes from a predehiscence level of 16 to 17% to near that of the external environment by the third week after the onset of shuck split (Kays 1977). While the oxygen concentration within the nut has a pronounced effect on kernel color during storage, it does not appear to represent a controlling factor over normal color development while the nut is on the tree. This conclusion is based on the absence of an oxygen concentration effect on color development and the relatively high oxygen concentration within the nut. Kernel color does, however, continue to darken after dehiscence and as a consequence, harvest and prompt drying gives much lighter colored nuts.

Due to the higher quality of the nuts (Resurreccion and Heaton 1987), considerable interest has been directed toward techniques that facilitate early harvest. Early harvest has been experimentally achieved using ethylene releasing compounds (Hinrich and Hopfer 1970) and ethylene gas (Finch 1937, Kays et al. 1975). Ethylene releasing compounds work equally well on fruits harvested with the shuck intact (Payne and Kays 1978). Use of ethylene is based on the apparent natural role of this gaseous hormone which is synthesized by the kernels, inducing dehiscence (Kays et al. 1975, Lipe and Morgan 1970, Lipe and Morgan 1972, Lipe and Morgan 1973). The high degree of leaf abscission that often accompanies the use of ethylene releasing compounds to accelerate normal dehiscence has precluded commercialization due to a significant reduction in yield the following year. An alternative method for early harvest is by shaking the trees rather violently as the shucks are just splitting. This practice results in the entire fruit (nut and shuck) being removed, thus an additional handling step is needed for mechanical removal of the shucks. Likewise, early harvested nuts generally require additional drying. Regardless, the superior color quality and potential for early sales prior to the bulk of the crop entering the market has made early harvest a common practice for some growers.

I) Weather Prior To and During Harvest. Early frost is a common problem in the northern-most areas of the pecan belt (and occasionally at higher elevations in the southwest) and results in a distinct discoloration problem. Frost causes the kernels to become intensely dark in color and have a bitter taste. Although the discoloration is located only in the surface cells, a commercial viable method for removal of the discoloration has not yet been developed.

The moisture level of the soil at harvest also has a pronounced effect on color. For example, Thompson et al. (1989) found that the lightest kernels sampled were from El Paso and the darkest from Baton Rouge and that the differences were related to field moisture conditions before harvest. Leaving nuts on moist soil for 7 days or less has been shown to substantially decrease color quality (Heaton et al. 1977). Losses in quality are especially critical when rainy, humid weather coincides with harvest.

POSTHARVEST FACTORS AFFECTING QUALITY

As with prior to harvest, a diverse array of factors can influence the postharvest quality of pecans. These include: a) temperature; b) oxygen concentration; c) moisture; d) light; e) shelling; f) packaging; g) handling; h) gases; i) cultivar; j) wholesale and retail conditions; k) insects; l) diseases; m) postharvest treatments; and other factors. Understanding the relationship between these factors and quality is essential for maintaining pecans in the best possible condition.

A) Temperature. Temperature is perhaps the single most critical environmental factor affecting the quality of nuts after harvest. This is because temperature affects the rate of chemical reactions; typically the higher the temperature the faster the reactions proceed. If pecans are harvested at their peak in quality, then changes in quality after harvest will be detrimental. Thus the higher the temperature the faster undesirable changes in quality will proceed.

Storage of pecans at low temperatures greatly minimizes undesirable color and flavor changes (Blackmon 1932, Blackmon 1933, Brison 1945, Heaton et al. 1977, Wells 1951). In general, the lower the storage temperature, the greater the storage life of the kernel. Temperatures above 4.4°C result in relatively rapid discoloration, while temperatures at or below -18°C will maintain quality for several years (Figure 7). Staleness

and rancidity can be detected after as little as one week at 37.8°C (Heaton et al. 1977), a temperature that is not uncommon in unrefrigerated transport trailers during the summer months.

Fluctuations in temperature can be especially undesirable when the product temperature is below the dew point temperature of the surrounding air. This routinely occurs when pecans are taken out of cold storage into ambient conditions. If the kernels are sealed within plastic bags or other water vapor resistant containers, the product temperature simply adjusts upward. However, if the nuts are exposed to the air, moisture will condense on the surface. Surface moisture increases the moisture content of the kernels while providing excellent conditions for mold growth, both of which are undesirable.

Another problem with postharvest temperature management is that in retail stores pecans are stored and marketed under non-refrigerated conditions. This practice greatly accelerates the rate at which quality is lost. Ideally, pecans should be maintained in the frozen food display cases, however, tradition mitigates against such a change. As a consequence, low oxygen package environments are used in an attempt to minimize the detrimental effect of high retail temperatures on quality.

B) Oxygen. Oxygen is known to be a major contributor to discoloration of pecan kernels (Kays and Wilson 1977) and to the development of rancidity. The detrimental effect of oxygen is concentration and temperature dependent. The higher the oxygen concentration (Figure 8), the more rapid the rate of discoloration. As the storage temperature increases at a given oxygen concentration, the rate of undesirable oxygen mediated changes (e.g., discoloration, rancidity) increases.

Low oxygen (controlled atmosphere) environments are used commercially for several horticultural crops, most notably apples and pears. This greatly extends the length of time that acceptable quality can be maintained after harvest. While there is a distinct beneficial effect of low oxygen on pecans, wholesale storage almost universally utilizes temperatures below 0°C. With low temperature storage, oxygen concentration is much less critical since the reaction rate of oxygen within the tissue is greatly inhibited. Although controlled atmosphere storage may afford minor benefits for pecans at low temperatures, it is not highly probable that the benefits would outweigh the substantial increase in expense.

Upon leaving the wholesale storage environment, product temperature increases substantially (i.e., 25 to 30°C), making low oxygen environments of distinct value. The easiest and most economical method for maintaining the kernels under a low oxygen environment at this stage is through the use of retail packages in which there has been a partial replacement of oxygen with nitrogen. The use of nitrogen appears to be superior to carbon dioxide in replacing oxygen (Sacharow 1971). The optimum oxygen concentration has not yet been established, but is thought to be in the 2% range at 21°C.

Pecan kernels, being comprised of live cells, require some oxygen for normal metabolic activity. Storage of kernels at very low oxygen concentrations is, therefore, undesirable and has a very pronounced detrimental effect on quality (Dull and Kays 1985, Dull and Kays 1988). At very low oxygen partial pressures, anaerobic conditions occur, changing the direction of the flow of carbon in the respiratory pathways toward the production of ethanol and aldehydes which give the kernels a distinct off-flavor.

The requirement of oxygen by the nuts coupled with the undesirable effect of excessive oxygen creates a packaging problem. Packaging materials must be selected that allow some oxygen movement through the material into the interior to prevent anaerobic conditions from occurring. Without a continual but low level of diffusion of oxygen into the package, the nuts which utilize oxygen in their normal respiratory processes, pull the internal concentration downward eventually reaching an anaerobic concentration. The question then is, what is the optimum diffusion rate for oxygen through the packaging material (Dull and Kays 1988)?

Current techniques for creating a low oxygen package environment utilize a partial vacuum on the package followed by purging with nitrogen gas just before closure. Although not overly precise, this technique tends to give packages which contain oxygen concentrations below 5% (Table 13) (Kays 1982). Use of vacuum storage will also reduce quality losses (Brison 1945), however, the effect is through the reduced oxygen partial pressure rather than the vacuum *per se* (Kays and Wilson 1977b).

C) Moisture. The metabolic rate of harvested seeds and nuts is very closely tied to their moisture content. Respiratory rate is commonly used as an indication of the general overall rate of metabolism. Hence, when respiratory rate is high there is a much more rapid loss of quality.

When the moisture content is reduced to below the level that is generally considered safe for storage, there is a pronounced decline in the respiratory rate (Figure 9) (Beaudry et al. 1985).

Rapid adjustment of the kernel moisture content in pecans after harvest is essential for quality maintenance. High moisture nuts are much more prone to discoloration, poor texture and mold growth. For example, at 6.75% moisture the percent of moldy kernels reached 100 within 4 weeks in contrast to mold free nuts when the moisture level was reduced to 4.15% (Bertrand and Wilson 1986). Typically, some drying is required for intact nuts after harvest in the southeast and all nuts after shelling that have been preconditioned (i.e., soaked or steam treated) or otherwise have an undesirably high moisture content.

Pecans should be stored at a kernel moisture content of 3.5% to 4.0% (Heaton and Woodroof 1970, Heaton et al. 1977, Woodroof 1979). To accomplish this, forced air drying is commonly used. Drying should not be attempted at temperatures above 38°C since exposure to excessive heat decreases quality. Drying is accelerated by elevated temperatures, increased air velocity, and a relative humidity of 60% or below. Over drying can also be detrimental in that breakage increases markedly.

The relative humidity of the air the nuts are exposed to after harvest is critical for maintaining the appropriate kernel moisture content. Pecans absorb or loose moisture depending upon their existing moisture content, chemical composition and the moisture content of the air in which they are held. Kernels stored at approximately 58% relative humidity (at 1.1 to 2.2°C) stabilize their moisture content at 3.5% which is considered to be optimal (Figure 10) (Heaton et al. 1977). The precise moisture-humidity relationship varies somewhat between cultivars (Donahaye and Navarro 1982, Heaton et al. 1977). During retail marketing, movement of water through the packaging material causes the nuts to adjust to the prevailing conditions. Prolonged exposures to high relative humidities can result in a progressive increase in kernel moisture content. Selection of packaging materials with a high diffusion resistance to water is therefore desirable.

D) Light. Light, especially in the red wave-lengths of the visible spectrum, is detrimental to the color of shelled pecans (Heaton and Shewfelt 1976). Increasing the intensity and/or exposure duration accelerates darkening of the kernels. Storage of shelled pecans in red cellophane containers decreased the rate of discoloration when compared to clear containers. The quantity and quality of light the nuts are exposed to during retail marketing varies between stores and the location of the nuts within a store (Kays 1982).

E) Shelling. A significant percentage of the pecan crop is retail marketed after the shell has been removed. In addition to being preferred by most buyers, shelling also substantially reduces the amount of storage space required. The shelling process can be separated into four general operations: conditioning the nuts; cracking the shell; separation of the kernel or kernel pieces from the shell; and redrying to 3.5% moisture.

During shelling it is advantageous to remove the cotyledons (kernels) as two intact pieces (halves) rather than fragmented into smaller sized pieces. Intact halves garner a higher price when sold and have a longer storage life than pieces (Woodroof and Heaton 1962). Hence, breakage represents a distinct form of quality loss.

To decrease the amount of kernel breakage, the intact nuts are normally "conditioned" via increasing the moisture content of the kernels. Conditioning makes the kernels more pliable and thus, better able to withstand the physical stresses imposed during cracking and subsequent shell separation steps (for a critique of cracking and shell separation see Kays 1991).

The most commonly used conditioning processes involves soaking the intact nuts in water. Typically, the nuts are held in large vats of water containing 1000 ppm chlorine for 1 to 2 hours and then held an additional 12 to 24 hours before cracking. A variation of this technique is to use hot water ($\sim$85°C) which allows decreasing the soaking time to 3-5 minutes followed by holding the nuts for 12 to 24 hours before cracking. The percentage yield of halves obtained using a water soak increased significantly with increasing water temperature (Forbus and Smith 1971). A disadvantage of both techniques is that considerable time is required, hence the nuts tend to be handled in batches rather than in a continuous stream (i.e., "in line") of product from the conditioner to the cracker (Forbus and Senter 1976).

An in-line process utilizing steam conditioning for 3 minutes at atmospheric pressure significantly increased the number of intact halves (i.e., 12 to 17%) over either of the water

soak methods (Forbus and Senter 1976). Both duration of exposure to steam and pressure appear to be critical variables. Excessive exposure duration results in considerably darkened kernels (Woodroof and Heaton 1961). Even with short exposure times (i.e., 3 minutes) some darkening occurs (Forbus and Senter 1976). A secondary benefit of steam conditioning is that the kernels are less susceptible to oxidation and hydrolytic deterioration during subsequent storage (Forbus and Senter 1976), thus decreasing the rate at which rancidity occurs (McGlamory and Hood 1951). Pecans that were heat treated (~88°C) also had a superior flavor quality rating after storage (Senter et al. 1984). Higher temperatures (i.e., 136 and 156°C) tended to disrupt the cells and gave a roasted flavor.

When nuts are harvested prior to dehiscence (a common practice in Israel) an additional step for shuck removal is required. The shucks are normally removed mechanically although the postharvest application of Ethrel will also facilitate removal (Payne and Kays 1978). Shuck removal followed by drying should be accomplished within 3 days of harvest or quality decreases and fungal infestation increases (Pastal et al. 1987).

F) **Packaging.** Packaging is a critical component in the handling, storage, transportation, and marketing of nuts in that the package should not only contain the nuts but also provide protection against damage, facilitate handling and communicate essential information. Packaging for pecans can be separated into two general classes - bulk containers that are commonly used for handling, storage and transport, and small individual retail packages. Storage and transportion/distribution containers differ from retail containers in size, shape, and construction material.

Pallet boxes and fiber bags are used extensively for intact nuts. Prior to shelling the kernels are protected from mechanical damage by the ridged shell which acts as a physical barrier. After removal from the shell, the kernels are much more susceptible to mechanical damage, thus small containers are generally used.

Plastic lined pallet boxes and smaller corrugated paper (cardboard) boxes are commonly used for kernels and pieces. These are used widely in that they are inexpensive, are collapsible thus requiring little space, are strong and can be obtained in a diverse array of shapes, size, and chemical compositions. Wax impregnated boxes or plastic liners within standard boxes are essential to prevent oil moving from the kernels into the paper.

A suitable retail package should be compatible with the handling system and the environment to which it will be exposed, be durable, and present the product in an attractive manner. For kernels, the package also needs to provide some protection against injury, prevent the entry of contaminants, retard moisture exchange between the external and internal environments, and be amenable to specialized treatments such as an altered internal gas composition. Many of the characteristics of the package are indirectly defined by the eventual buyer. Typically, retail packages are filled by wholesalers or specialized middlemen rather than at the retail store due to the cost of the equipment.

Current practices for shelled pecans involve marketing the kernels packed loose in flexible 4 mil laminated polyethylene-polyolefin packages (Kays 1982). These packages are generally purged with nitrogen prior to sealing, giving internal oxygen concentrations of below 5%. Oxygen concentration and temperature represent the two most critical environmental parameters with regard to unfavorable color and flavor changes after harvest (Kays 1979, Kays and Wilson 1977).

The use of modified gas atmospheres in retail packages has been an important technological advance in maintaining quality after harvest (Kays 1982). Modified atmospheres utilize a much reduced oxygen concentration thus decreasing the number of oxygen molecules available for undesirable chemical reactions. Most packaging materials allow some movement of oxygen and water molecules through the surface. Recent evidence indicates that excessively low permeability rates cause unfavorable quality changes in unprocessed nuts held at room temperature (Dull and Kays 1988). This is caused by the requirement of a small amount of oxygen for normal metabolic processes. Once processed (i.e., cooked in some manner) the nuts are no longer alive and, as a consequence, can be stored in the absence of oxygen allowing the use of containers that are essentially impermeable to oxygen (e.g., glass, metal).

Current packaging materials and the internal packaging atmospheres created represent a significant positive step in quality maintenance; however, considerable work is needed to refine the specific requirements. Since the nuts are

utilizing oxygen from within the package and oxygen is moving slowly into the package, selection of the correct packaging material must take into account: a) the rate of oxygen utilization by the nuts; b) the amount of nuts within the package; c) the oxygen transmission rate of the packaging material; d) the surface area of the package; and e) the difference in the oxygen concentration between the interior and exterior of the package. When properly balanced and the packaged product is held within a relatively narrow temperature range, the oxygen concentration can be maintained at or very near the desired level. Factors such as temperature, nut moisture level, and cultivar, however, can influence the final oxygen concentration. Packaging materials with oxygen transmission rates between 0.02 and 0.39 cc O_2.100 cm^{-2}.24 hr^{-1} have been tested (Dull and Kays 1988). The very high and low end of the scale resulted in significant losses in quality during storage. The best material tested thus far was a cellophane coated with polyvinylidene chloride that had a oxygen transmission rate of ~0.08 cc O_2.100cm^{-1}.24 hr^{-1}. Clearly, considerable more research is needed to ascertain the optimum conditions and the appropriate packaging material and protocol.

Vacuum packaging of kernels has been shown to decrease the potential for mechanical damage that may occur during transport and retail sales (Dull and Kays 1988). As the vacuum is applied at closure, the packaging material collapses around the kernels within the bag, holding them securely in place.

In contrast to fresh nuts, processed pecans can be stored in containers that are essentially impermeable to oxygen and water. Such containers include foil pouches, vacuum sealed glass jars and metal containers.

Unshelled pecans are generally packaged in cellophane bags containing 1 to 3 pounds of nuts, with no attempt to alter the internal gas atmosphere. Plastic mesh bags are also used. Since the mesh generally comes in a continuous roll, they have the advantage over pre-cut bags in that the volume of nuts contained can be readily altered.

G) Handling. Between harvest and eventual utilization by the consumer, pecan go through a series of handling steps. Mechanical damage represents a serious means of quality loss during handling. One analyses of pecans found in retail markets around the United States showed that 50.6% of the nuts were inferior to the grade indicated on the package (Williams et al. 1973). A major portion (i.e., 37%) of the quality loss was due to mechanical damage to the kernels. In addition to breakage decreasing the grade and subsequent value, mechanical damage also accelerates the rate at which quality is lost. For example, shell damage during harvesting has been shown to result in increased kernel darkening (Reid and Heaton 1977).

Analysis of mechanical damage after retail packaging indicated that kernels at the recommended storage moisture level can withstand extensive physical stress (Dull and Kays 1988). When dropped 10 times from a height of 5 feet onto a concrete floor, only 14% of the halves per package were broken. Likewise, vibrational stress did not cause appreciable damage. The data appear to indicate that most breakage occurs prior to packaging.

Susceptibility to mechanical damage is known to increase when the kernels are excessively dry. Use of vacuum packaging can eliminate most mechanical damage during marketing (Dull and Kays 1988).

H) Gases. Exposure to certain volatiles, whether organic or inorganic in origin, can result in extensive quality loss. Perhaps the most dramatic effect is seen with the accidental exposure of pecans to ammonia. Ammonia, once the refrigerant of choice, remains widely used and with the phasing out of halogen refrigerants, its use is anticipated to increase. Problems arise when leaks develop in the refrigeration system and ammonia escapes into the storage area. Exposure of pecans to ammonia can transform the kernels from a state of optimum color to a black unmarketable product within minutes (Medlock 1931, Medlock 1933, Rose 1939, Woodroof and Heaton 1966). The extent to which the kernels are discolored varies with the moisture content of the nuts, concentration of the gas, cultivar, length of exposure (Kays and Wilson 1977), temperature and age of the nut (Woodroof and Heaton 1966). The discoloration is restricted to the outer skin of the kernels with the interior remaining normal. After adequate aeration the ammonia dissipates and the flavor is not adversely affected. The color, however, renders the nuts unmarketable for nearly all traditional uses.

Ammonia induced discoloration can be partially reversed using dilute acid solutions (Kays and Wilson 1977c); however, the kernels never regain their original color. Other compounds can be used to reduce the oxidation state of iron atoms in the

surface testa (von Wandruseka et al. 1980) reversing much of the discoloration. Unfortunately, those tested thus far either are toxic or have an undesirable effect on flavor.

Another problem during storage is the absorption of odors from other products or non-biological sources. Similar to sugar dissolving in water, many gases will partition into the lipids of the pecan. This effect is especially true for lipophilic compounds. When their odor is distinct it can significantly reduce the flavor quality of the nuts. Care therefore should be taken when pecans are held in mixed storage with other products.

I) Cultivar. At harvest the kernels of pecan cultivars vary in color, flavor, composition, and other attributes (e.g., size, shape). During the postharvest period distinct differences have been found for color stability (Kays and Wilson 1978) and the rate at which the lipid component becomes rancid (Rudolph 1971). At present, cultivar differences in quality stability represent a postharvest variable that is largely ignored owing to the absence of information on useful treatments. The least stable cultivars; however, should be rapidly handled and placed under optimum conditions (i.e., storage temperature and relative humidity).

J) Existing Wholesale and Retail Conditions. The majority of the pecans at the wholesale level are stored under relatively good conditions. Shelled pecans are typically dried to 3.5 to 4.0% moisture and stored at 0°C. Low oxygen storage environments are not utilized and would be of only minimal benefit if the appropriate temperature conditions are met.

At the retail level, conditions are considerably more variable. In a preliminary study, most pecans were packaged loose in cellophane pouches of 64 to 80 gm (Table 13) (Kays 1982). The level of breakage (28 to 37%) was comparable to that reported previously (37%) (Williams et al. 1973). The internal air volume of the packages ranged from ~50 cc in 80 gm packages to ~100 cc in 64 gm packages (Kays 1982). The internal oxygen concentration was found to vary between 1.65 and 4.6% (Table 13). Moisture levels in the nuts were low, ranging from 2.6 to 3.4%, although comparable to levels reported previously (Williams et al. 1973). The respiratory rate of the kernels reflected, in part, differences in kernel moisture level, ranging from 0.77 mg CO_2, $Kg^{-1}.hr^{-1}$ (3.4% H_2O) to 0.3 mg CO_2 Kg^{-1} hr^{-1} (2.6% H_2O).

The environmental conditions in air-conditioned retail stores in which the nuts were obtained also varied significantly (Table 14) (Kays 1982). Ambient temperatures at the location of the nuts within the stores varied between 22 and 25°C, a temperature range that is known to accelerate the rate of quality loss. Light, which is detrimental to nut quality, varied in intensity and quality (Table 14), depending to a large extent on location within the stores. Pecans placed near windows were exposed to three times the intensity of those further back in the stores. Collectively these results indicate that there is substantial room for improvement in the retail marketing of pecans which should translate into extended quality maintenance.

K) Insects. Pecans represent an excellent food base for a number of storage insects. Larvae that feed on pecan kernels in storage are produced by the almond moth (*Ephestia cautella* Wlkr.) and the Indian-meal moth (*Plodia interpunctella* Hbr.). Beetles which feed on pecans are the saw-toothed grain beetle (*Oryzaephilus surinamensis* L.), cadelle beetles (*Tenebroides mauritanicus* L.), the confused flour beetle (*Tribolium confusum* Duv.), and the red flour beetle (*Tribolium castaneum* Hbst.) (Woodroof 1979). Likewise, insects that are brought into storage from field infestations can also be a significant problem (e.g., pecan weevil larvae *Curculio caryae*, Horn). Postharvest insects consume portions of the kernels and leave bodies, frass and webbing in the nuts. This decreases the weight of the product, its aesthetic quality and in some cases its safety.

Storage insect problems vary between inshell and shelled nuts. Shelled nuts allow ready access, however, their presence can generally be readily detected. In contrast, inshell nuts are more resistant to infestation, but the presence of the insect is often difficult to establish without removal of the shell. As a consequence, insects and insect damaged nuts are more likely to be found at the retail level in inshell nuts.

Storage insects can be readily controlled by storage of the nuts below 9°C (Woodroof 1979). Likewise, fumigation can be used to kill existing insects [e.g., carbon dioxide and ethylene oxide (9:1) or ethylene dichloride and carbon tetrachloride (7:3), or methyl bromide] (Woodroof 1979).

L) Diseases. As indicated in the section on preharvest diseases, pecan kernels generally have considerable inoculum present by the time they have been harvested. For example, *Alternaria* sp. have even been isolated from dormant buds (Knox 1980). The primary difference between preharvest and postharvest mycoflora is in the species that predominate. Prior to harvest, *Penicillium* was the most prevalent genus of fungi (69%) followed *Aspergillus* (12%) (Hanlin 1985). During the postharvest period *Asperigillus* (including Eurotium) predominated accounting for 66% of the isolates while *Penicillium* now only made up 19%.

Reducing the kernel moisture level to 3.5% to 4.0% is the single most important factor in preventing mold development. Temperature reduction also decreases the rate of mold development (Bertrand and Wilson 1986). The presence of moldy kernels within the storage container did not increase the percent moldy kernels, indicating that the nuts were sufficiently inoculated at harvest for rapid mold development if conditions were conducive.

Some disinfection of bacteria and mold can be accomplished through the use of chlorine in the conditioning water prior to cracking (Heaton et al. 1977), however, the concentration of chlorine is difficult to maintain due to the level of organic material. Likewise, fumigation of shelled or unshelled nuts can be used to reduce the level of microorganisms. The fumigant propylene oxide is typically applied to nuts held within specialized chambers. This allows precise control over the temperature, pressure and relative humidity during treatment and increasing the effectiveness of the fumigant.

M) Postharvest Treatments. A number of treatments have been tested for their ability to decrease the rate of quality loss after harvest. These include antioxidants, color modification, irradiation, and treatments to alter the internal atmosphere of unshelled nuts.

The propensity of pecans to become rancid is strongly influenced by the degree of unsaturation of fatty acids present. Certain chemicals of both artificial and natural origin also appear to affect the rate at which rancidification occurs. Tocopherols are one such group of natural antioxidants which are found in the pecan. Of the four chemical forms present (α, β, γ, and δ), γ-tocopherol predominates (Yao 1990). The concentration of tocopherol is at a peak ($\sim$600 $\mu g\ gm^{-1}$ oil) around 6 weeks prior to kernel maturity (Rudolph 1971) and declines to 100-200 $\mu g.gm^{-1}$ at harvest. With storage at ambient temperatures, the tocopherol concentration continues to decline during storage (Yao et al. 1990).

Based upon a declining tocopherol concentration with increasing rancidity and the known role of tocopherols as antioxidants, the application of tocopherols to pecan kernels and oil was tested. When added to pecan oil, the keeping time increased in a linear fashions with increasing concentration up to 800$\mu g.gm^{-1}$ oil at which point a plateau was reached (Figure 11) (Rudolph 1971). King (1986) found that the application of α-, γ and a mixture of tocopherols to kernels as a 0.02 or 0.05% solution, significantly decreased the rate of color loss and preserved the flavor during storage.

The application of exogenous antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), nordihydroyguaiacetic acid (NDGA), Tenox 20A and propyl gallate have been used with generally minimal or no success (Anon 1958, Changa et al. 1988, Godkin et al. 1951, King 1988). In some instances BHA has been found to impart a bitter flavor to the nuts (Heaton et al. 1977).

Exposure of the kernels to heat (90-100°C), whether from a dielectric source or steam, decreases the rate of color and flavor loss during storage (Nelson et al. 1985, Senter et al. 1984). It is thought that thermal treatments inhibit enzymatic mediated fatty acid oxidation through partial deactivation of certain critical enzymes.

Pecan color modification has only been explored to a limited extent. Kernel discoloration can be partially reversed using acidulants, thus enhancing the color grade of the kernels (Kays and Wilson 1977). Dilute solutions of phosphoric acid were the most effective of the acidulants tested, producing lighter kernels without a significant effect on flavor. Concentration, length of exposure, pre-wetting and rinsing after treatment are all critical factors affecting the successful manipulation of kernel color. Strong acidic solutions can be detrimental not only to flavor but also color.

Acidification of ammonia damaged kernels can also partially reverse the discoloration, depending in part on the severity of the damage. Treated commercial samples of ammonia damaged pecans increased their color grade from oil stock ($\sim$\$0.16 per pound) to the amber USDA classification (Kays and Wilson 1977).

Odell (1976) explored the possibility of altering to a marketable condition the color of pecans damaged by frost prior to dehiscence. Both water extraction of the soluble discolored pigments and testa removal were tried with some success, although the commercial feasibility has not been established.

Irradiation of pecans was tested as a possible means of mold control (Chang et al. 1988). Exposure to O.6 KGy decreased *Aspergillus* counts; however, quality was appreciably compromised.

CONCLUSIONS

While our understanding of the basic chemistry of the pecan and causes of quality losses have increased substantially, analysis of pecans at the retail level underscore the fact that considerable improvements are needed. In some instances, it is a matter of applying existing knowledge while in others, additional research is essential. The postharvest technology of pecans is in a perpetual state of transition. Techniques are continually being improved and technological advances in other areas (e.g., plastics) often have a significant impact on our industry. Keeping pace with the latest improvements in an essential requisite for success in a highly competitive nut crop industry.

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Table 1. Composition of pecan kernels (Adams 1975, Senter 1976, Watt and Merrill 1963).

Calories (cal g^{-1})	687	Zn (mg $100g^{-1}$)	7.02
Water (%)	3.0	Mo (mg $100g^{-1}$)	0.06
Lipid (%)	73.0	Sr (mg $100g^{-1}$)	0.58
Protein (%)	9.4	Ba (mg $100g^{-1}$)	0.56
Dietary Fiber	2.2	Na (mg $100g^{-1}$)	0.44
Sugars (%)	3.9	P (mg $100g^{-1}$)	450
Starch (%)	0	K (mg $100g^{-1}$)	460
Ash (%)	1.6	Ca (mg $100g^{-1}$)	5.8
Cu (mg $100g^{-1}$)	1.08	Mg (mg $100g^{-1}$)	140
Fe (mg $100g^{-1}$)	2.20	Vitamin A (I.U.)	130
Co (mg $100g^{-1}$)	trace	Thiamin (mg $100g^{-1}$)	0.86
Cr (mg $100g^{-1}$)	1.20	Riboflavin (mg $100g^{-1}$)	0.13
Al (mg $100g^{-1}$)	0	Niacin (mg $100g^{-1}$)	0.9
Mn	3.28	Ascorbic acid (mg $100g^{-1}$)	2
B (mg $100g^{-1}$)	0.62		

Table 2. Variation in pecan kernel composition due to cultivar (Odell et al. 1971).

Cultivar	Moisture %	Ash %	Lipid %	Protein %
Aggie	3.34	1.38	68.04	10.35
Apache	3.30	1.54	74.01	9.16
Barton	4.33	1.75	64.13	11.19
Burkett	3.02	1.79	67.35	13.03
Butterick	3.54	1.81	72.17	9.28
Caddo	4.37	1.72	67.61	9.50
Choctaw	2.87	1.85	71.16	10.21
Comanche	3.71	1.86	65.19	12.78
Cowley	4.29	1.61	76.23	8.88
Delmas	3.63	1.91	66.19	12.64
Elliot	3.61	1.77	65.63	10.53
Golden	3.20	1.60	74.32	7.85
Gormely	3.17	1.57	70.11	9.35
Green River	3.02	1.38	76.12	9.44
Jack Ballard	3.71	1.58	71.97	7.22
Kentucky	3.41	1.35	71.04	10.06
Major	3.39	1.35	71.51	10.63
Mohawk	3.39	1.58	70.81	9.79
Moneymaker	3.43	1.59	66.76	10.88
Mount	2.85	1.69	74.41	10.50
Oklahoma	3.88	1.53	60.27	15.02
Peruque	3.16	1.37	75.73	8.28
Schley	3.48	1.67	72.44	9.38
Shawnee	5.21	1.80	65.83	10.68
Sioux	2.69	1.55	73.95	10.44
Squirrel	3.58	1.49	63.35	11.68
Stuart Seedling	3.54	1.88	65.90	8.13
Texhan	3.49	1.81	64.49	10.88
Wichita	2.77	1.48	75.45	9.46

Table 3. Variation in pecan kernel composition due to year of production (Odell et al. 1971).

Cultivar	Year[a]	Moisture %	Ash %	Lipid %	Protein %
Barton	1	2.63	1.43	78.0	11.85
	2	5.29	1.38	69.4	9.97
	3	4.67	1.79	71.0	9.12
Desirable	1	1.62	2.00	73.1	11.87
	2	8.21	2.29	60.3	15.20
	3	-----	-----	-----	------
Graking	1	3.28	1.58	73.4	10.98
	2	-----	-----	-----	------
	3	-----	-----	-----	------
Hayes	1	3.22	1.39	73.6	9.88
	2	4.74	1.66	68.9	11.30
	3	3.93	1.79	63.0	9.28
Nugget	1	2.61	1.94	70.4	12.75
	2	4.69	1.53	69.1	11.30
	3	-----	-----	-----	------
Patrick	1	3.22	1.39	71.5	11.28
	2	4.72	1.50	68.0	10.50
	3	3.54	1.83	61.7	15.47
San Saba	1	2.28	1.65	75.6	10.31
Improved	2	4.70	1.55	71.6	9.78
	3	3.39	1.52	71.3	10.52
Success	1	2.60	2.00	73.6	10.44
	2	5.58	2.02	60.0	13.4
	3	2.83	1.79	69.91	9.50
Stuart	1	2.46	1.57	78.7	8.20
	2	4.46	1.26	69.9	9.38
	3	2.33	1.43	76.6	8.08
Schley	1	3.04	1.60	70.3	9.19
	2	4.73	1.43	70.3	9.88
	3	3.43	1.48	68.4	10.71
Texas Prolific	1	3.04	2.47	73.2	9.22
	2	4.78	1.53	71.0	8.13
	3	3.24	1.61	63.9	9.78
Western	1	2.69	1.50	77.9	8.82
	2	4.28	1.58	71.8	9.10
	3	3.20	1.56	69.61	10.82

[a]Years 1-3 = 1967-1969.

Table 4. Fatty acid composition of pecans (Senter and Horvat, 1977, 1978).

Abbreviation	Systemic name	Common name	Concentration[a] $g.100g^{-1}$ nut meat	% of Total Fatty Acids
Saturated fatty acids				
10:0	decanoic	capric	<0.2[a]	<0.28
12:0	dodecanoic	lauric	<0.2	<0.28
14:0	tetradecanoic	myristic	1.2	1.66
15:0	pentadecanoic		<0.2	<0.28
16:0	hexadecanoic	palmitic	4.1	5.64
17:0	heptadecanoic	magaric	0.3	0.37
18:0	octadecanoic	stearic	1.5	2.08
20:0	eicosanoic	arachidic	0.4	0.61
21:0	heneicosanoic		<0.2	<0.28
Unsaturated fatty acids				
12:1	dodecenoic		<0.2	<0.28
14:1	tetradecenoic		<0.2	<0.28
14:2	tetradecadienoic		<0.2	<0.28
15:1	pentadecenoic		<0.2	<0.28
15:2	pentadecadienoic		<0.2	<0.28
16:1	hexadecenoic	palmitolic	0.4	0.58
16:2	hexadecadienoic		<0.2	<0.28
17:1	heptadecenoic		0.3	0.36
17:2	heptadecadienoic		<0.2	<0.28
18:1	octadecenoic	oleic	37.9	52.29
18:2	octadecadienoic	linoleic	22.5	31.08
18:3	octadecatrienoic	linolenic	1.5	<0.28
20:1	eicosenoic		0.5	0.75
20:2	eicosodienoic		<0.2	<0.28

[a]Means of six cultivars.

Table 5. Cultivar variation in pecan kernel fatty acid concentration (Odell et al. 1971).

Cultivar	Palmitic %	Stearic %	Oleic %	Linoleic %	Linolenic %
Aggie	5.6	1.6	64.8	26.7	1.4
Apache	5.4	2.2	71.8	19.3	1.3
Barton	6.0	1.6	70.0	19.3	1.3
Burkett	5.8	1.5	58.6	32.6	1.6
Butterick	6.3	1.9	69.3	21.1	1.5
Caddo	7.0	1.6	64.4	25.6	1.3
Choctaw	5.7	1.6	74.0	18.0	1.1
Cowley	5.4	2.6	61.2	28.9	1.7
Delmas	6.8	1.3	54.1	36.2	1.5
Desirable	5.8	1.4	68.4	23.3	1.2
Elliot	5.3	2.3	67.0	24.4	1.4
Golden	5.8	1.8	72.6	18.7	1.2
Gormely	5.6	2.3	72.1	18.7	1.3
Green River	5.5	1.9	71.9	19.6	1.4
Hardy Giant	6.0	2.1	71.3	19.5	1.2
Hayes	6.1	1.3	53.4	37.4	1.9
Jack Ballard	6.1	2.0	63.7	26.8	1.5
Kentucky	6.3	2.0	73.3	17.0	1.0
Major	6.5	1.2	68.8	22.3	1.3
Mohawk	5.8	1.7	64.5	26.5	1.8
Moneymaker	6.1	1.5	64.5	26.9	1.0
Mount	5.1	2.1	67.8	23.3	1.8
Nugget	5.7	1.7	73.3	18.3	1.2
Oakla	5.0	1.8	73.3	18.9	1.1
Oklahoma	5.9	1.6	66.6	24.1	1.8
Patrick	5.9	1.5	59.6	31.2	1.8
Peruqua	6.4	2.0	69.1	21.4	1.1
San Saba Improved	5.6	1.8	62.6	28.5	1.4
Schley	6.4	1.3	63.5	27.5	1.3
Shawnee	6.3	2.1	64.7	25.1	1.7
Sioux	6.1	1.7	65.5	25.3	1.5
Squirrel	6.6	1.9	59.0	31.0	1.5
Stuart	6.3	1.6	68.9	21.9	1.3
Stuart Seedling	5.7	1.7	64.4	26.7	1.4
Success	6.0	1.8	64.8	26.0	1.4
Texas Prolific	6.2	1.8	63.7	26.9	1.6
Texhan	7.3	1.9	61.9	27.4	1.7
Western	6.8	1.9	54.3	35.4	1.7
Wichita	6.7	1.9	71.5	18.4	1.3
68L1	4.9	1.9	78.1	14.0	1.1

Table 6. Variation in pecan kernel fatty acid composition due to year of production (Odell et al. 1971).

Cultivar	Year[1]	O/L	Fatty Acid				
			Palmitic	Stearic	Oleic	Linoleic	Linolenic
Barton	1	1.34	11.3	2.7	48.7	36.2	1.1
	2	5.23	7.4	2.3	73.4	14.1	1.9
	3	4.01	5.4	1.8	73.1	18.2	1.5
	4	3.29	6.0	1.6	70.0	21.3	1.2
Hayes	1	1.79	10.0	1.3	56.9	31.8	.4
	2	3.04	8.0	2.4	66.0	21.7	1.1
	3	2.32	6.6	1.6	62.9	27.1	1.8
	4	1.43	6.1	1.3	53.4	37.4	1.9
Patrick	1	1.34	10.7	1.6	50.3	37.4	.3
	2	3.13	7.4	2.2	66.5	21.2	1.9
	3	3.04	5.5	2.0	68.0	23.0	1.6
	4	1.91	5.9	1.5	59.6	31.2	1.8
San Saba Improved	1	1.70	8.7	2.0	68.0	23.0	1.6
	2	4.35	6.1	2.9	71.7	16.5	2.0
	3	1.82	5.9	1.7	58.5	32.1	1.8
	4	2.20	5.6	1.8	62.6	28.5	1.4
Schley	1	2.02	8.5	1.6	59.7	29.6	.6
	2	1.96	8.3	2.2	57.7	29.5	1.7
	3	1.78	7.4	2.1	56.7	31.9	1.9
	4	2.31	6.4	1.3	63.5	27.5	1.3
Stuart	1	1.65	8.5	1.6	55.3	33.6	1.0
	2	2.56	8.1	2.4	62.6	24.4	2.0
	3	1.82	6.0	1.8	58.3	22.1	1.8
	4	3.15	6.3	1.6	68.9	21.9	1.3
Success	1	1.60	7.7	1.5	55.9	34.9	1.0
	2	3.55	6.8	2.5	69.5	19.6	1.4
	3	1.47	6.9	1.9	53.0	36.2	2.0
	4	2.49	6.0	1.8	64.8	26.0	1.4
Texas Prolific	1	1.29	8.4	1.1	51.0	39.6	.4
	2	1.60	7.9	3.0	53.6	33.6	1.7
	3	1.72	5.9	1.9	57.4	33.3	1.6
	4	2.37	6.2	1.8	63.7	26.9	1.6
Western	1	1.25	10.6	1.3	48.8	39.2	.3
	2	2.43	7.6	2.9	62.1	25.5	1.5
	3	1.44	7.7	2.0	52.1	36.2	2.1
	4	1.53	6.8	1.9	54.3	35.4	1.7

[1]Years 1-4 = 1966 through 1969.

Table 7. Concentration of tocopherol in pecan kernel oil from 70 cultivars and selections (Odell et al. 1971).

Cultivar or Line	Tocopherol ($mg.g^{-1}$ oil)	Cultivar or Line	Tocopherol ($mg.g^{-1}$ oil)
Aggie	327	Success	376
Apache	253	Texas Prolific	324
Barton	375	Texhan	305
Barton	410	Western	490
Burkett	237	Wichita	325
Butterick	207	61H	226
Caddo	379	461	493
Caddo	246	464	240
Choctaw	221	465	225
Comanche	323	467	326
Cowley	233	472	231
Delmas	287	481	454
Desirable	313	493	246
Elliot	457	495	285
Golden	405	497	354
Gormely	266	502	412
Green River	253	503	333
Hayes	324	504	298
Jack Ballard	353	507	213
Kentucky	234	511	456
Major	290	513	306
Mohawk	353	518	370
Moneymaker	290	519	388
Mount	263	542	277
Oklahoma	248	551	362
Patrick	337	552	426
Peruque	294	571	282
San Saba Improved	413	572	238
Schley	309	581	323
Schley	309	583	255
Shawnee	369	591	285
Sioux	291	593	215
Squirrel	242	600	131
Stuart	393	2412	464
Stuart Seedling	323	4610	308

Table 8. Amino acid composition of pecan kernels (Merideth 1974).

Amino Acid	$mg.100g^{-1}$	Amino Acid	$mg.100g^{-1}$
Essential amino acids			
Isoleucine	299	Phenylalanine	387
Leucine	482	Tyrosine	268
Lysine	276	Threonine	241
Methionine	168	Tryptophan	161
Crystine	93	Valine	359
		Total	2733
Non-essential amino acids			
Arginine	1349	Glutamic acid	1760
Histidine	261	Glycine	425
Alanine	384	Proline	406
Aspartic acid	830	Serine	413
		Total	5827

Table 9. Volatile compounds emanating from raw (Rudolph 1971) and roasted pecans (Wang and Odell 1972).

Raw	Roasted	Roasted
Alcohols	Carbonyls	Alcohols
1-Heptanol	Ethanal	Ethanol
1-Hexanol	Propanal	1-Pentanol
1-Octanol	Butanal	1-Hexanol
1-Pentanol	Pentanal	1-Heptanol
Aldehydes	Hexanal	1-Octanol
Amylfuran	Heptanal	Lactone
Hexanol	Octanal	γ-Octalactone
Heptanol	2-Hexenal	
Nonanal	2-Heptenal	
Octanal	2-Decenal	
Lactones	2-Undecenal	
α-Caprolactone	Acrolein	
	2,4-Heptadienal	
	2,4-Decadienal	
	Furfural	
	Glyoxal	
	Pyruvaldehyde	
	Diacetyl	
	2,3-Pentanedione	
	Basic compounds	
	Pyridine	
	2-Methylpyrazine	
	2,5-Dimethylpyrazine	
	2,6-Dimethylpyrazine	
	2,3-Dimethylpyrazine	
	2-Ethyl-6-methylpyrazine	
	2-Ethyl-5-methylpyrazine	
	2,3,5-Trimethylpyrazine	
	2,5-Dimethyl-3-ethylpyrazine	
	Acids	
	Acetic acid	
	Propionic acid	
	Pentanoic acid	
	4-Methyl-pentanoic acid	
	Hexanoic acid	
	Heptanoic acid	
	Octanoic acid	

Table 10. Kernel iron content and color after soaking in aqueous 2% phosphoric acid or 0.5m stannous chloride[a] solution (after von Wandruszka et al. 1980).

Cultivar	Total Fe (ppm)	Surface Fe (ppm)	Color Rating (L)	Color Change with 0.5m $SnCl_2$ (%)	Color Change with 2% H_3PO_4 (%)
Schley	78.3	14.7	31.6	4.7	6.9
Witchita	84.6	15.3	30.9	7.4	3.9
Frotcher	99.3	19.1	26.5	10.6	11.7
Stuart	94.5	20.9	29.9	17.7	3.3

[a]Toxic.

Table 11. USDA size classifications for intact kernels (after USDA 1969).

Size classification for halves	Number of halves per pound
Mammoth	250 or less
Junior mammoth	251-300
Jumbo	301-350
Extra large	351-450
Large	451-550
Medium	551-650
Small (topper)	651-750
Midget	751 or more

Table 12. USDA size classifications for kernel pieces (after USDA 1969).

Size Classification	Maximum diameter (will pass through round opening of following diameter)	Minimum diameter will not pass through round opening of following diameter)
Mammoth pieces	No limitation	8/16"
Extra large pieces	9/16"	7/16"
Halves and pieces	No limitation	7/16"
Large pieces	8/16"	5/16"
Medium pieces	6/16"	5/16"
Small pieces	4/16"	2/16"
Midget pieces	3/16"	1/16"
Granules	2/16"	1/16"

Table 13. Nut and packaging conditions of 3 major brands of shelled pecan halves collected from retail stores in Athens, Georgia (after Kays 1982).[a]

Brand	Type of kernel	Wt package (gm)	% grade #1[b] (% by wt)	Excess gas[c] volume in package (cc)	Package O_2 conc. (%)	Package CO_2 conc. (%)	Kernel[d] respiratory rate (mg CO_2 $.Kg^{-1}$ $.hr^{-1}$)	Kernel moisture level (%)	Packaging material
A	Grade 1	80	73.4	50	4.48	0.28	0.34	3.0	4 mil laminated polyethylene and polyolefin
B	Grade 1	64	63.1	100	1.65	1.91	0.77	3.4	4 mil laminated polyethylene and polyolefin
C	Grade 1	64	67.5	100	4.6	0.44	0.30	2.6	4 mil laminated polyethylene and polyolefin

[a]All measurements represent means of 3 packages per brand.
[b]Based on broken pieces only.
[c]Based on the internal gas volume before and after applying a partial vacuum (360 mm Hg).
[d]Respiratory rate at 21% O_2, 21°C.

Table 14. Marketing conditions of pecans in four retail supermarkets (after Kays 1982).

Store	Temperature (0°C)	Light intensity (F.C.)	Type of light
1	25°	54	fluorescent
2	22°	175	sunlight + fluorescent
3	24°	77	fluorescent + sunlight
4	25°	58	fluorescent

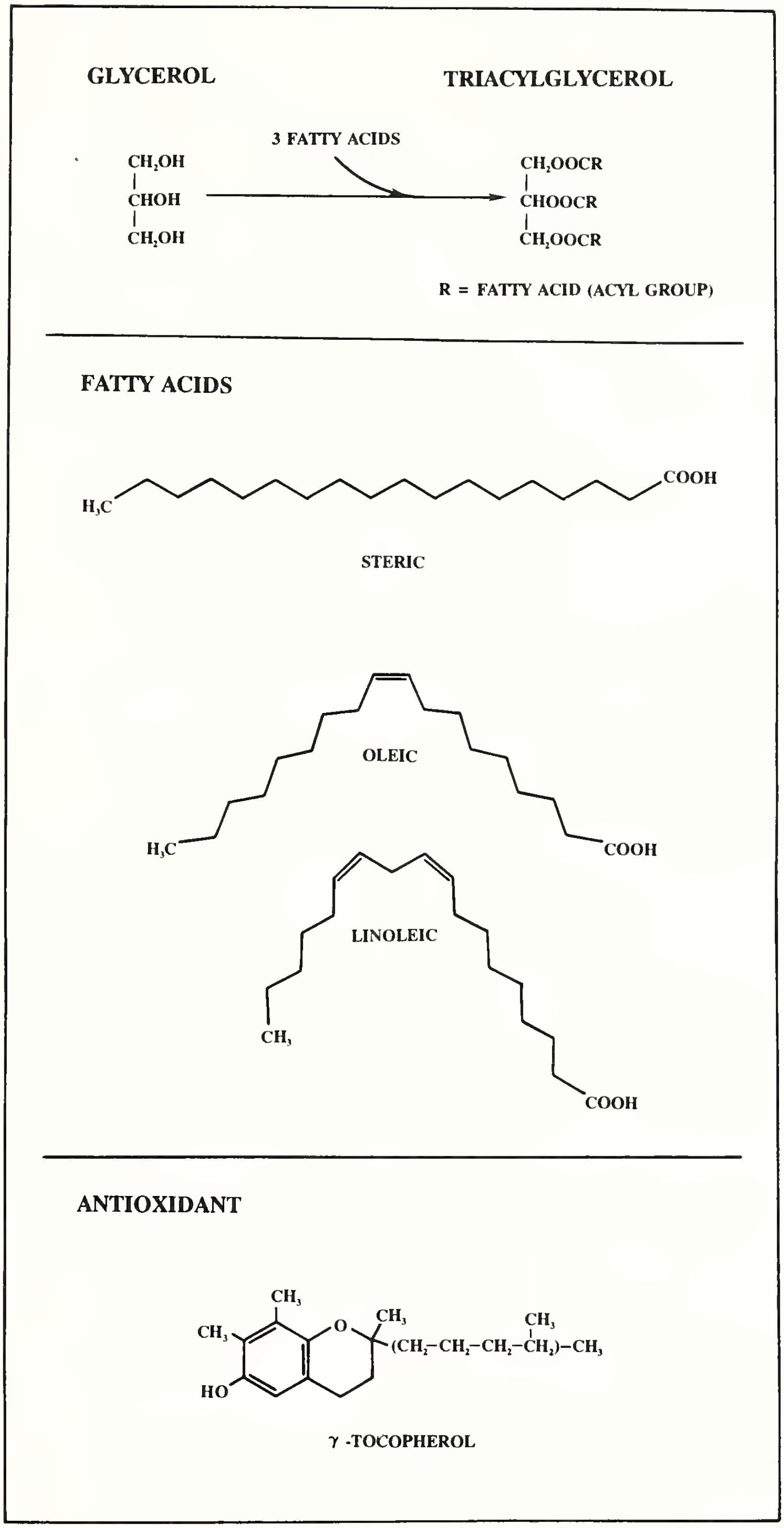

Figure 1. Base structure of: glycerol; a triacylglycerol; three fatty acids with different levels of saturation; and γ-tocopherol, a naturally occurring antioxidant.

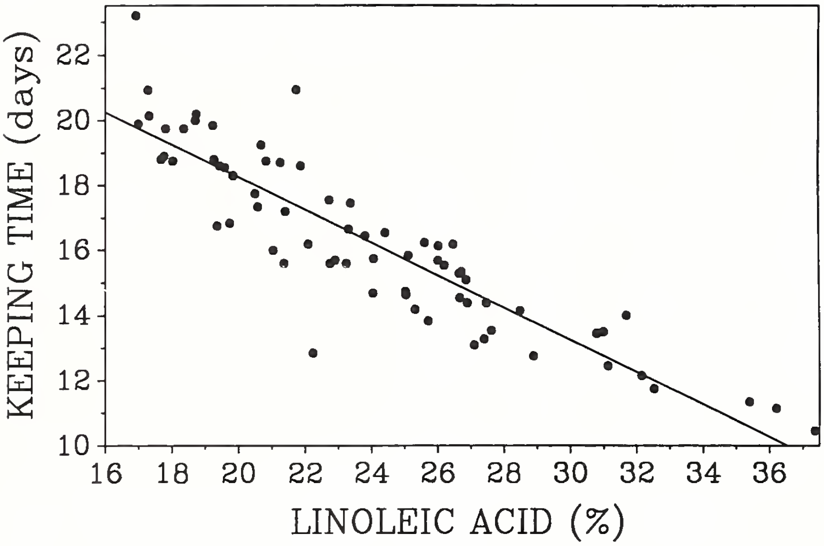

Figure 2. Relationship between the concentration of linoleic acid and keeping time of pecan oil (data from 70 cultivars or selections) (after Rudolph 1971).

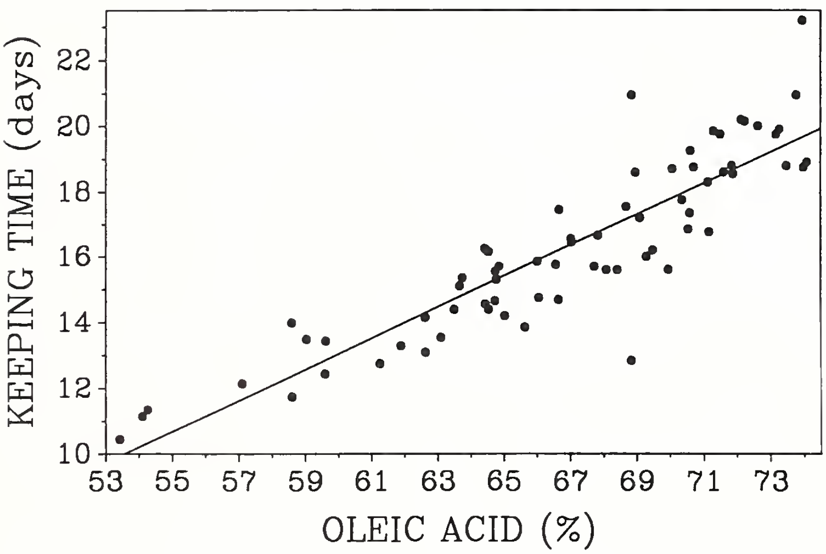

Figure 3. Relationship between the concentration of oleic acid and keeping time of pecan oil (data from 70 cultivars or selections) (after Rudolph 1971).

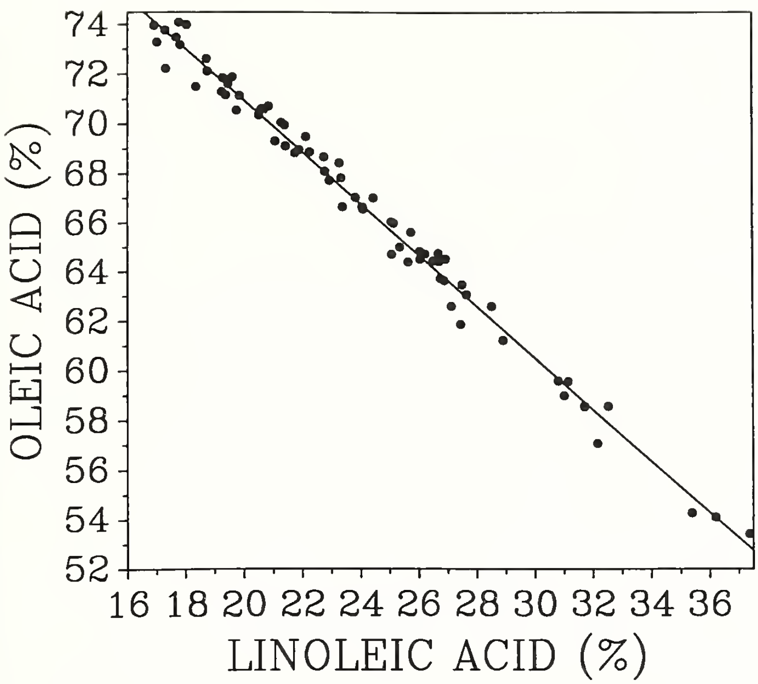

Figure 4. Relationship between oleic and linolecic acid concentration in pecan lipids (after Rudolph 1971).

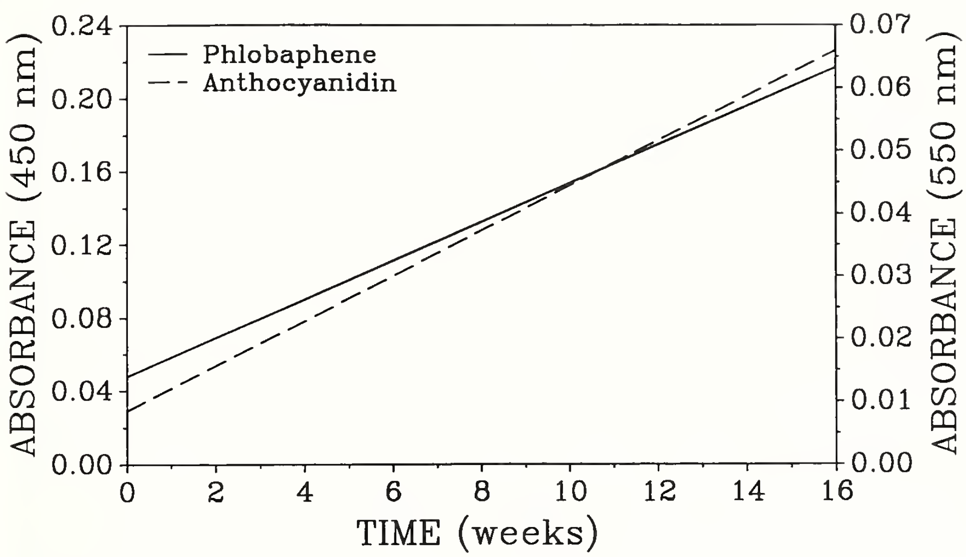

Figure 5. Changes in the content of phlobaphene and anthocyanidin during storage (after Senter 1976b).

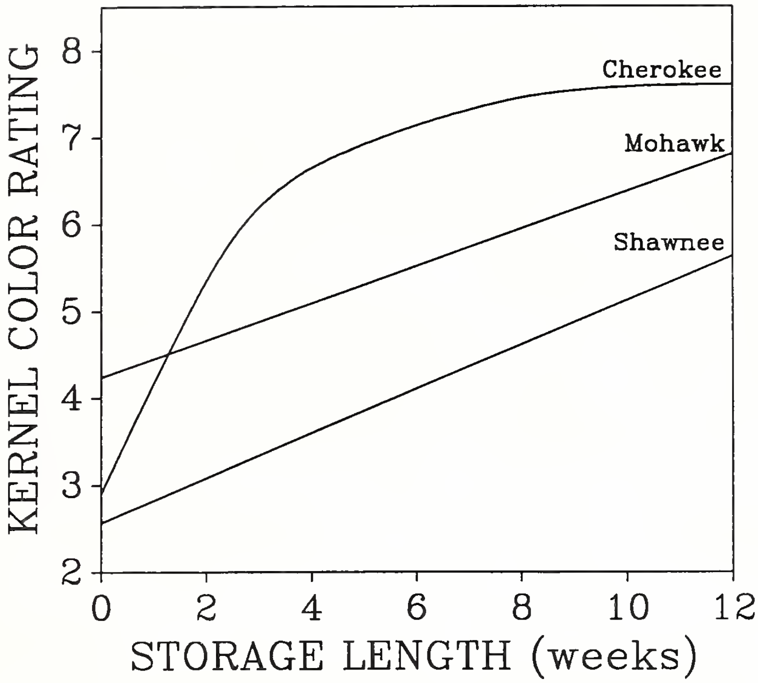

Figure 6. Changes in color quality with storage duration for three cultivars (the higher the kernel color number the lover the quality) (after Kays and Wilson 1978).

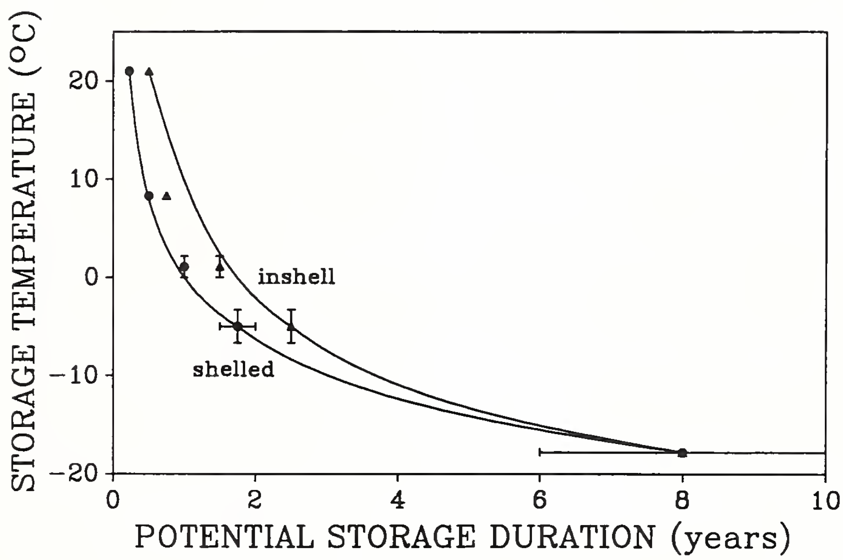

Figure 7. The effect of storage temperature on the potential storage duration of shelled and in shell pecans (after Woodroof 1979).

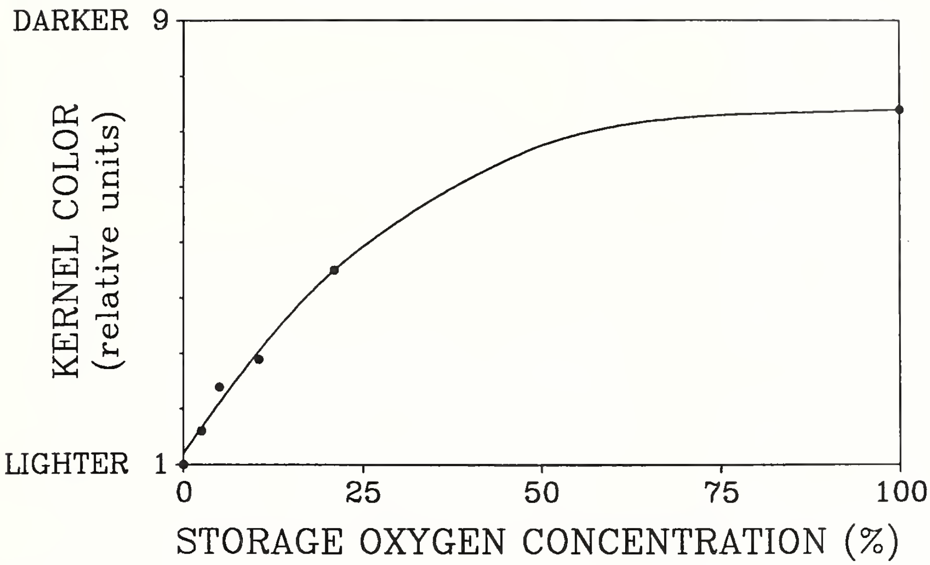

Figure 8. The effect of storage oxygen concentration on kernel color after 21 days at 38°C (after Kays and Wilson 1977).

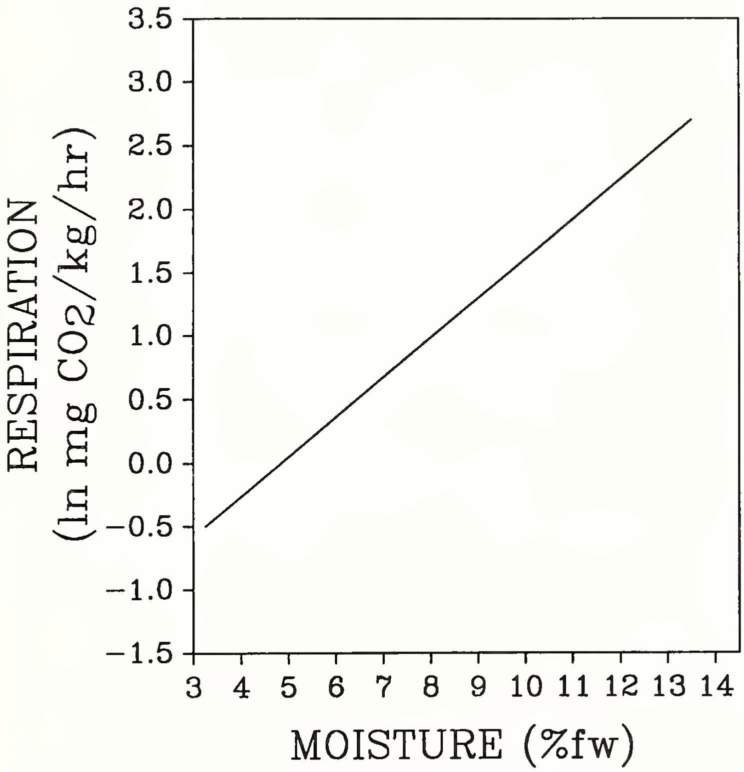

Figure 9. The relationship between pecan kernel moisture content and respiratory rate (Beaudry et al. 1985).

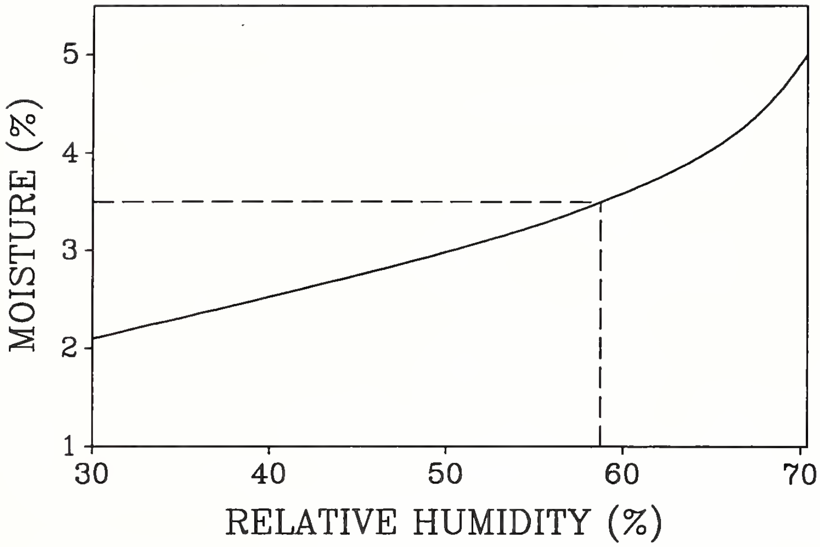

Figure 10. The relationship between storage environment, relative humidity and kernel moisture content (after Heaton et al. 1977). Kernel moisture content stabilizes at 3.5% when held in an environment with 58% relative humidity at 1.1 to 2.2°C.

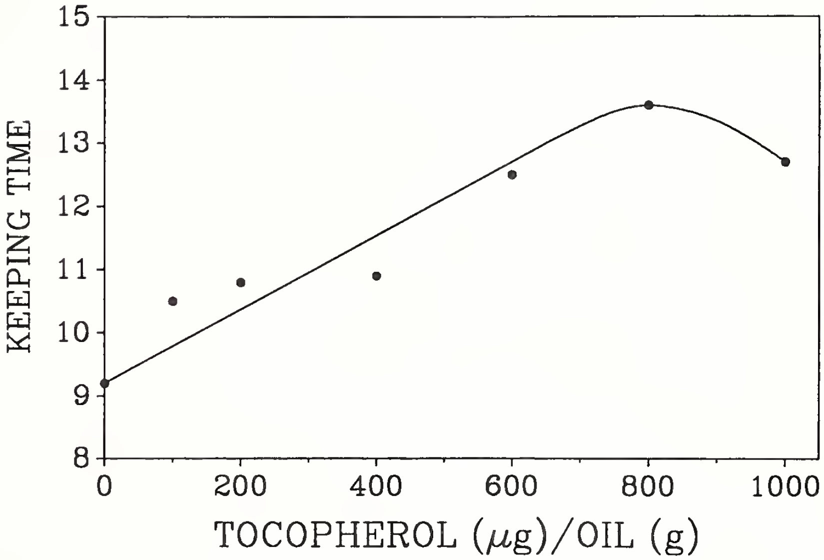

Figure 11. The effect of added tocopherol to pecan oil from the cultivar 'Stuart' on keeping time (after Rudolph 1971).

ALTERNATIVE PECAN PRODUCTS: PROBLEMS AND POTENTIAL

Charles R. Santerre[1], R. Dixon Phillips[1], Robert Y. Ofoli[2] and Jerry N. Cash[3]

ABSTRACT

A by-product of pecan chopping, pecan meal, was extruded using a twin-screw extruder in attempts to produce a remanufactured pecan piece which would possess enhanced value for secondary pecan processors, Milling of pecan meal with a colloidal mill rendered a light colored paste which combined with starch, soybean flour and water in the barrel of a twin-screw extruder to produce a pelletized pecan piece. Further development will be necessary to increase the pecan flavor, lighten the color, and remanufactured pecan pieces.

INTRODUCTION

Pecans are sold as a premium tree nut and have many uses as a component in the formulations of baked goods, confections, ice creams, and snack foods. Unfortunately, pecan sales have not kept pace with sales of other tree nuts such as walnuts or almonds as a result of inadequate marketing strategies (Karst 1989, Mizelle 1989) and variable product quality (Hubbard et al. 1988). Developing a strategy whereby pecan by-products are processed into value-added, alternative pecan products may increase the value of pecans. For this strategy to be successful, a niche for the new product or product-line must be determined followed by product development, test-marketing, product refinement and promotion. The whole process must be precisely coordinated through all phases of development.

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Economic losses occur during the chopping of pecans to produce pieces for further food manufacturing. A by-product of the chopping operation, pecan meal, is produced at a rate of 3-6% depending upon the type of equipment used, the condition of the pecans, and the rate of chopping (Santerre 1989). Pecan meal has a value which is less than one forth the value of pecan pieces. This low value of meal is significant when considering the fact that an estimated 13-27,000 kg/week are produced in the southeastern U.S. Unfortunately, there is not an adequate market for meal and this by-product is often discarded.

An option for utilization of pecan meal is to press the meal to produce oil, however, pecan oil is expensive and does not compete economically with the less expensive oils. Attempts should be directed at converting pecan meal into a value-added product, such as a remanufactured pecan piece which will offer several advantages over pecan pieces. The secondary processor (i.e., baker, confectioner, ice cream maker, etc.) of pecan pieces often finds objectionable quality due to off-flavors (as a result of mold or rancid flavor development), darkening, presence of shell and interstitial shell, and the presence of pecan weevil larvae. The production of a remanufactured pecan piece could provide a pecan piece with enhanced quality for secondary processors. Some of the advantages of a remanufactured pecan piece produced from pecan meal include: 1) a consistent size and shape; 2) elimination of harmful shell fragments; 3) extended shelf life following addition of stabilizers and preservatives to the formulation; 4) low cost of raw product (i.e., meal); 5) elimination of pecan weevil larvae; and 6) reduced off-flavors which are found occasionally in pecan halves.

A remanufactured pecan piece must meet several quality requirements before it would be considered useful as a food ingredient. First, the final product must have a nut-like texture with good integrity when added to high moisture environments (i.e., greater than 40% moisture as in a cookie batter or bread dough). Second, it must have a characteristic pecan flavor and mouthfeel. Third, the piece must have an appearance (including size, shape and color) which is similar to pecan kernels and desirable to consumers. Fourth, the cost of producing the remanufactured pecan piece must be feasible in relation to it's final value.

In order to develop a remanufactured pecan piece, the composition of pecans must first be explored. Pecans are composed of 68% lipid, of which 92% is unsaturated (McCarthy and Matthews 1984). Pecans

are generally dried to between 3.5% and 5.0% moisture and contain approximately 7.7% protein (Tables 1 & 2). The formulation to produce a piece, will require a binder(s) such as starch and/or soy bean flour which will also reduce the lipid content of the final product and incorporate a nut-like texture. Several steps will be required during preparation of the piece in order to gelatinize the starch, eliminate the raw flavor in the soybean flour, mix the pecan meal with the other components and compress all of the ingredients into a pelletized form. A flexible piece of equipment which can handle all of these requirements is the co-rotating, twin-screw extruder. With an extruder of this type, the starch, soybean flour and pecan meal can be wetted, mixed, sheared, cooked, cooled and compressed into a final form in a single operation.

The objectives of this research have been divided into 2 phases as follows:

Phase I

A) To determine the upper limit of lipid concentration in the extrusion of mixtures of soybean flour, starch, pecan meal, pecan paste, water and pecan oil to produce a remanufactured pecan piece from pecan by-products.

B) To determine the optimal ratio of each component in an extrudate to be used for producing a pecan piece which has nut-like characteristics.

Phase II

A) To mill pecan meal into a paste which maintains a pecan-like color and flavor and can be incorporated into an extruder to produce a light colored pecan piece.

B) To determine an approach which will reduce the time-temperature exposure of the pecan paste while maintaining the texturization of starch and the cooked flavor of the soybean flour during extrusion of a remanufactured pecan piece.

C) To assess progress in the formulation of a remanufactured pecan piece and develop further strategies in it's successful development.

MATERIALS AND METHODS

Phase I

Extrusion was used to process 14 pecan formulations. The formulations were as follows:

1. 100% soybean flour
2. 50% soybean flour; 50% raw pecan meal
3. 50% soybean flour; 50% raw pecan meal
4. 50% soybean flour; 50% raw pecan meal
5. 5% soybean flour; 55% raw pecan meal
6. 40% soybean flour; 50% raw pecan meal; 10% corn starch
7. 60% soybean flour; 40% raw pecan meal
8. 50% soybean flour; 40% roasted pecan meal; 10% corn starch (>water)
9. 50% soybean flour; 40% roasted pecan meal; 10% corn starch (<water)
10. 50% soybean flour; 40% roasted pecan paste; 10% corn starch
11. 40% soybean flour; 50% roasted pecan paste; 10% corn starch
12. 50% soybean flour; 50% corn starch
13. 25% soybean flour; 50% roasted pecan meal; 25% corn starch
14. 30% soybean flour; 40% roasted pecan oil; 30% corn starch

Each exudate was prepared using a Clextral BC45 co-rotating, twin-screw extruder (Clextral, Inc., Odessa, FL) configured as shown in Table 3. The operating parameter wre: 3 dies of 4mm diameter; die face cutter with blade 4 CLX; air gap, 3 mm. Other conditions are given Tables 4 & 5. Extrudates were partially dried using a 80°C convection oven. Following drying, extrudates were analyzed for color, moisture and texture.

'Roasted and raw pecan pastes' were prepared from pecan meal which was obtained from commercial suppliers, then roasted at 176°C for 30-40 min. or maintained raw, ground to a paste using a Morehouse Stone Mill, Model M-MS-3 (Fullerton, CA) with a 0.254 in. stone clearance. 'Pecan oil' was obtained by pressing 'roasted pecan meal' in a Carver Hydraulic Press, Model C (Menomonee Falls, WI) at 2400 psi for 10-15 min. Defatted soy flour (Soyafluff 200W; Central Soya, Inc., Fort Wayne, IN) and/or corn starch (BakaSnak; National Starch

and Chemical Co., Bridgewater, NJ) was added to produce a product with a nut meat texture and to reduce the lipid concentration from 65% for raw meal.

Phase II

Extrusion was conducted using a Baker Perkins MPF-50D (APV Baker, Grand Rapids, MI) co-rotating, twin-screw extruder with the screw configuration (L/D 25) given in Table 6. The operating parameters were: water feed setting, 4 (83.3 mL/min.); dry ingredient feed setting, 65 (348 g/min.); pecan paste feed setting, 1.5 (100 g/min.); screw speed, 200-220 RPM; Torque, 50%; die diameter, 3 mm; die pressure, 240 psi (single die); die length, 5.0 cm.

The dry ingredients (starch and soybean flour) were added through the first port of the extruder barrel, whereas, pecan paste was pumped through a port which was 2/3rds down the barrel using a Moyno pump. Starch and soybean flour were mixed in a 1:3 ratio in three 22.7 kg portions in a tumble cone mixer for 10 min. and the portions were then combined.

'Pecan paste' was prepared by grinding frozen, raw pecan meal using a Colloid, Toothed Mill, Type MZ-110/A (Fryma, Inc., Edison, NJ) which was set at 1/2 turn open from fully closed. Product temperature following milling was between 45.7°C and 51.3°C and maintained a dark brown color. Pecan paste was immediately place at 32°C and stored for 2 months until further processing.

Tristimulus color of the samples was measured on the Gardner Color Analyzer. A yellow standard tile was used (standard tile; L=78.46, a=-2.20, b=23.40). The sample cell was filled with pecan pieces and the cell was covered to prevent stray light.

Texture was measured on the Instron Universal Testing Instrument (Model No. 1122) by measuring the amount of force required to compress 1.5 g of pecan pieces down to 2 mm with a compression anvil. A 500 kg load cell was used with the full scale set at 200 kg full scale for samples 1 to 7 and at 50 which equals 500 kg for samples 8 to 14. Crosshead speed was set to 10 mm/min. Chart speed was 50 mm/min. For sample #12, only 1.0 g sample was tested due to it's puffed size. Texture measurements were reported as N/g pecan pieces.

Moisture was measured using CEM Automatic Volatility Computer. The microwave settings were as follows: mode=1; power=60%; time=10 min. Each sample was ground in the 8 oz. cup with the Oster blender and a 3.3 g sample was analyzed.

Oil Content was measured using the Goldfisch Method (Gould 1976) with a sample size of 5.0 g an extraction time of 17 hr using 50 mL of peteoleum ether.

RESULTS & DISCUSSION

Phase I

The color of all of the extrudates was unacceptably dark due to the high temperatures during the extrusion and/or milling process(es). The pecan paste used in this phase was unacceptably darkened during the milling process. The paste also had a less intense pecan flavor than the roasted pecan meal. Color measurements for the various extrudates are given in Table 7. L-value readings are indicative of the lightness of the samples. The range of L-values is 1 to 100 with a reading of 1 being black and a reading of 100 being white. The L-value of an extruded pecan piece should be greater than 50 if the product is to resemble pecan piece.

Due to the problems associated with extruding high fat products (i.e., difficulty in conveying through the barrel and loss of product consistency), the maximum level of pecan meal which could feasibly be extruded was 40% (db). Therefore, a formulation which includes 40% pecan meal containing 65% lipid, appears to be most desirable in terms of final texture. The extrudate from this formulation would have a final lipid content of 26% (db). In this study, the formulations which were composed of less than 40% pecan meal or paste possessed a suprisingly good texture. Formulations which incorporated corn starch with the soybean flour appeared to provide a better final texture than soybean flour alone. Instron compression forces for the 14 extrudates are given in Table 8. Extrudates composed of 50% soybean flour plus 40% roasted pecan meal or pecan paste plus 10% corn starch gave the best compression readings and were subjectively found to have a better nutmeat mouthfeel.

This study indicates that using a pecan paste to produce a pecan piece may offer a couple advantages. First, using pecan paste instead of pecan meal would improve consistency of the extrudate. Second, the use of a ground pecan paste instead of a pecan meal would eliminate the

problems associated with shell pieces in the final produce. Unfortunately, grinding of shell and interstitial shell pieces which are present in the meal, may also increase the astringency of the final paste. A strategy may be employed where the pecan paste would be injected into the previously mixed, heated and cooled (texturized) corn starch plus soybean flour mixture at a later stage of the extrusion process (possibly at the die). This would reduce the time-temperature exposure of the pecan paste and reduce the color darkening which we observed as well as reduce the loss of pecan flavor volatiles which occurred during Phase I. By reducing the loss of pecan flavor volatiles during processing the intensity of the pecan flavor in the final pecan piece would increase. For this strategy to be successful, the pecan paste would need to be produced at a lower temperature to incur less darkening.

Phase II

Grinding of pecan meal using a cooloidal mill produced a pecan paste at a low enough temperature to produce a paste with desirable color and flavor. In addition, the milling procedure also allowed enough of the pecan lipid to remain bound in fat globules, thereby reducing separation of the oil. An additional benefit was noted by the reduction of shell pieces during grinding. Shell fragments which were added to the mill were reduced to a grit-like substance which would be more of an annoyance to consumers than a health risk.

The extruded pecan piece produced in this phase had a final composition of 44.4% soybean flour; 21.5% pecan paste; 19.3% water and 14.8% starch (wb). If the extrudate is dried and water is reduced to 4% in a similar manner to pecans, the final composition would be 52.4% of soybean flour; 25.3% pecan paste; and 17.5% starch. Unfortunately, the Moyno pump used in this study did not deliver a constant flow of pecan paste into the extruder barrel. Paste injected into the barrel was successfully incorporated into the starch and soybean flour matrix. It is also important to note that the paste was incorporated at a point in the extruder following wetting, mixing and heating of the starch and soybean flour mixture. The screw configuration chosen for this phase of the study appeared to produce to much shear to pre-gelatinized starch which was responsible for loss of texture. In addition to destroying the starch texture, the high shearing action appeared to release the pecan lipid from the fat globules and produce an oily extrudate. The mean compression force for 4 samples was 1193.4 N/g. The color of the extrudate for this phase was also unacceptable. The mean tristimulus color measurements for 3 replicates was as follows: L-value=20.22; a-value=3.84; and b-value=4.35. Further work is necessary to determine the effect of reduced barrel heating and shear forces on the color of the extrudate.

The successful production of a remanufactured pecan piece will significantly impact a struggling pecan industry and may result in the output of a potentially important value-added food ingredient.

ACKNOWLEDGEMENTS

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Table 1. Nutritional composition of dried, non-roasted pecan halves (McCarthy and Matthews, 1984).

Portion: 100 grams (3.53 oz.)			Water weight: 4.80 g		
Calories	667		Pyridoxine-B6	0.188	mg
Protein	7.75	g	Cobalamin-B12	0	μg
Carbohydrates	18.2	g	Folacin	39.2	μg
Dietary Fiber	6.50	g	Pantothenic acid	1.70	mg
Lipid-Total	67.7	g	Vitamin C	2.00	mg
Lipid-Saturated	5.42	g	Vitamin E	3.15	mg
Lipid-Monounsaturated	42.2	g	Calcium	36.1	mg
Lipid-Polyunsaturated	16.8	g	Copper	1.19	mg
Cholesterol	0	mg	Iron	2.13	mg
Vitamin A-Carotene	12.8	RE[1]	Magnesium	128	mg
Vitamin A-Preformed	0	RE	Phosphorus	291	mg
Vitamin A-Total	12.8	RE	Potassium	392	mg
Thiamin	0.848	mg	Selenium	5.09	μg
Riboflavin	0.128	mg	Sodium	0.926	mg
Niacin	0.887	mg	Zinc	5.47	mg

[1]RE=Retinol Equivalents.

Table 2. Nutritional composition of oil roasted, non-salted pecan halves (McCarthy and Matthews, 1984).

Portion: 100 grams (3.53 oz.)			Water weight: 4.20 g		
Calories	685		Pyridoxine-B6	0.164	mg
Protein	6.95	g	Cobalamin-B12	0	μg
Carbohydrates	16.16	g	Folacin	34.5	μg
Dietary Fiber	6.50	g	Pantothenic acid	0.413	mg
Lipid-Total	71.2	g	Vitamin C	0.4840	mg
Lipid-Saturated	5.71	g	Vitamin E	3.11	mg
Lipid-Monounsaturated	44.4	g	Calcium	33.6	mg
Lipid-Polyunsaturated	17.6	g	Copper	1.20	mg
Cholesterol	0	mg	Iron	2.11	mg
Vitamin A-Carotene	3.18	RE[1]	Magnesium	142	mg
Vitamin A-Preformed	0	RE	Phosphorus	294	mg
Vitamin A-Total	3.18	RE	Potassium	359	mg
Thiamin	0.305	mg	Selenium	100.0	μg
Riboflavin	0.112	mg	Sodium	0.909	mg
Niacin	0.795	mg	Zinc	5.50	mg

[1]RE=Retinol Equivalents.

Table 3. Extruder configuration for Phase I.

Barrel Length (mm)	Screw Type[1]	Location
200	50P	Inlet Feeder
100	35P	(Dry and Wet)
50	25P	
50	15P	
50	MD/BL	
100	50P	
100	35P	
100	25P	
100	15P	
50	-15RS	
100	15P	Die

[1] Screw Type: 50P=50 mm pitch; 35P mm pitch; 25P=25 mm pitch; 15P=15 mm pitch; MD/BL=mixing discs/bilobal; -15RS=slotted with reversing 15 mm pitch.

Table 4. Extruder operating parameters for Phase I, samples 1 to 7.

Sample No.[1]	1	2	3-4	5	6	7
Water (%)	80	70	80	80	60	90
Water (g/min.)	212	188	212	212	162	237
Temperatures (°C):						
Zone 1	22	26	33	36	39	39
Zone 2	90	90	125	124	150	150
Zone 3	140	187	180	180	209	210
Zone 4	140	90	90	90	90	90
Die Pressure & Bearing Bar Press. (bar)	22	10	12	10	12	13
Screw Speed (RPM)	150	154	250	250	115	114
Feeder Speed (RPM)	17	57	58	58	58	58
Throughput (g/min)	454	---	704	704	704	704

[1] Sample No.:
1. 100% soybean flour
2. 50% soybean flour; 50% raw pecan meal
3. 50% soybean flour; 50% raw pecan meal
4. 50% soybean flour; 50% raw pecan meal
5. 45% soybean flour; 55% raw pecan meal
6. 40% soybean flour; 50% raw pecan meal; 10% corn starch
7. 60% soybean flour; 40% raw pecan meal

Table 5. Extruder parameters for Phase I, samples 8 to 14.

Sample No.[1]	8-9	10-11	12	13	14
Water (%)	100	100	50	100	100
Water (g/min.)	272	272	136	272	272
Temperatures (°C):					
Zone 1	41	42	13	25	27
Zone 2	150	150	151	252	151
Zone 3	210	210	210	187	189
Zone 4	90	90	140	90	90
Die Pressure & Bearing Bar Press. (bar)	10	14	50	13	23
Screw Speed (RPM)	110	115	142	103	104
Feeder Speed (RPM)	18	41	36	52	52
Throughput (g/min)	704	704	704	704	704

[1] Sample No.:

8. 50% soybean flour; 40% roasted pecan meal; 10% corn starch (> water)
9. 50% soybean flour; 40% roasted pecan meal; 10% corn starch (< water)
10. 50% soybean flour; 40% roasted pecan paste; 10% corn starch
11. 40% soybean flour; 50% roasted pecan paste; 10% corn starch
12. 50% soybean flour; 50% corn starch
13. 25% soybean flour; 50% roasted pecan meal; 25% corn starch
14. 30% soybean flour; 40% roasted pecan oil; 30% corn starch

Table 6. Extruder configuration for Phase II.

Zone	Temperature Barrel (°C)	Temperature Product (°C)	Barrel Length (mm)	Screw Type[1]	Location
1	11.8	15.7	250	FS	Dry Feed Inlet[2]
2	53.5	50.7			Water Inlet
3	110.7	109.1	76	30F	
4	138.5	126.3	33	60R	
			75	SL	
			43	60F	
5	64.1	79.6	50	SL	
			22	90P	
			33	45R	
			75	SL	
6	29.6	63.5	43	60F	
			50	SL	
7	15.2	---	76	30F	Pecan Paste Inlet
			75	SL	
8	15.2	30.2	43	60F	
			50	SL	
			22	90P	
9	15.2	33.0	33	45R	
			50	SL	
10	---	30.2	50	Die	Die

[1] Screw Types: FS=feed screw; 30F=30 degree forwarding paddle; SL=single lead screws; 60R=to degree reversing paddle; 90P=90 degree mixing paddle; 45R=45 degree reversing paddle.
[2] Dry Feed: Starch and soybean flour mixture.

Table 7. Tristimulus color of remanufactured pecan pieces in Phase I.

	Sample[1]	Color[2] L-value	a-value	b-value
1.	100% SBF	42.53	4.35	16.05
2.	50% SBF; 50% RaPM	38.27	3.95	11.47
3.	50% SBF; 50% RaPM	39.46	3.32	11.42
4.	50% SBF; 50% RaPM	38.35	3.67	11.19
5.	45% SBF; 55% RaPM	36.67	3.46	10.25
6.	40% SBF; 50% RaPM; 10% CS	39.46	3.18	10.17
7.	60% SBF; 40% RaPM	32.76	4.91	8.40
8.	50% SBF; 40% RoPM; 10% CS (> water)	25.81	4.06	5.36
9.	50% SBF; 40% RoPM; 10% CS (< water)	23.48	3.87	4.72
10.	50% SBF; 40% RoPP; 10% CS	26.49	4.87	6.75
11.	40% SBF; 50% RoPP; 10% CS	24.31	4.23	5.70
12.	50% SBF; 50% CS	49.99	5.27	17.32
13.	25% SBF; 50% RoPM; 25% CS	18.05	2.46	2.19
14.	30% SBF; 40% RoPO; 30% CS	34.60	3.50	11.98

[1] SBF=soy bean flour; RaPM=raw pecan meal; CS=corn starch; RoPM=roasted pecan meal; RoPP=roasted pecan paste; RoPO=oil from roasted pecan meal.
[2] Standard Tile L=78.46; a=-2.20; b=23.40.

Table 8. Moisture and shear force of remanufactured pecan pieces in Phase I.

	Sample[1]	Moisture (%)	Compression Force (N Force/g product)
1.	100% SBF	20.22	875.1
2.	50% SBF; 50% RaPM	6.24	499.8
3.	50% SBF; 50% RaPM	5.02	732.1
4.	50% SBF; 50% RaPM	4.89	564.5
5.	45% SBF; 55% RaPM	5.36	713.4
6.	40% SBF; 50% RaPM; 10% CS	5.82	470.4
7.	60% SBF; 40% RaPM	9.16	992.7
8.	50% SBF; 40% RoPM; 10% CS (> water)	7.24	1992.3
9.	50% SBF; 40% RoPM; 10% CS (< water)	12.42	1246.6
10.	50% SBF; 40% RoPP; 10% CS	5.94	1460.2
11.	40% SBF; 50% RoPP; 10% CS	8.23	441.0
12.	50% SBF; 50% CS	12.11	421.4
13.	25% SBF; 50% RoPM; 25% CS	12.29	992.7
14.	30% SBF; 40% RoPO; 30% CS	10.60	2433.3

[1] SBF=soy bean flour; RaPM=raw pecan meal; CS=corn starch; RoPM=roasted pecan meal; RoPP=roasted pecan paste; RoPO=oil from roasted pecan meal.

PECAN MARKETING IN THE UNITED STATES

Wojciech J. Florkowski[1] and E. Eugene Hubbard[1]

ABSTRACT

Domestic marketing of pecans is of increasing importance because of expanding pecan production and competition from other tree nuts. Market structure adjustments specific to pecan industry are associated with the size of marketing margins. The competitive position of pecan industry is influenced by pecan industry promotion programs, storage, import and export of pecans. Pecan pricing is a complex issue because of the industry's heterogeneity, number of varieties, timing of sales, variable quality, etc. Pecan industry needs additional information about prices and quantities sold of pecans during harvest to improve market efficiency.

AN OVERVIEW OF THE PECAN INDUSTRY

The pecan is native to the United States. Groves of native pecans can be found in the southwestern states of Texas, Louisiana, and Oklahoma. However, cultivated varieties of pecans dominate commercial pecan production in the United States. Cultivated varieties grow well from Texas to southern Illinois and Indiana, and from California to North Carolina, but commercial production is concentrated in the southwestern and southeastern states.

Georgia is the leading pecan producing state and its position is determined by the production of improved varieties. Texas, New Mexico, and Oklahoma also produce large quantities of improved pecans. The largest producers of native and seedling pecans include Texas, Louisiana, and Oklahoma. In recent years, pecan production has been expanding in the western states of Arizona and California. In Georgia, new pecan orchards enter bearing age (Hubbard et al. 1988) and will increase the supply of pecans with desired shell-out ratio, color, and flavor.

The importance of pecans to state and local economies varies from state to state and fluctuates in response to changes in commodity prices. The importance of pecan production increases during periods of low agricultural prices because pecans are considered a high value crop. However, the value of pecans fluctuates from year to year in response to changing production and pecan supply.

Year-to-year changes in value of the pecan crop are substantial (Table 1). In general, fluctuations in the value of native and seedling pecans exceed the value changes of improved varieties. The difference is associated with the size of the crop i.e., in short years the value of native and seedlings increases, and the quality of pecans i.e., the shell-out ratio (low for native and seedlings), color of kernels, and disease damage. Fluctuations differ also among states and, in the case of improved varieties, are smaller in states with larger output than in states with limited pecan production.

Consumption Trends

For decades pecans were consumed in larger per capita quantity than any other tree nuts in the United States. However, the dominant position of pecans in tree nut consumption deteriorated as competition from other tree nuts increased. By 1970, walnuts surpassed pecans in per capita consumption (Figure 1) as a result of steady expansion of walnut production in California. California walnut producers supplied sufficient quantities of nuts to maintain the leading position of walnuts in per capita terms until the beginning of the 1980's. Since then, California almonds have been consumed in the largest per capita quantities.

The changing consumption patterns reflect the expansion of tree nut production as well as concerted efforts to market a quality product. Almonds which were an obscure tree nut in the 1950's are currently dominating tree nut consumption. The position of pecans deteriorated, although the general level of per capita consumption was in the mid-1980's similar to that of the early 1960's (Figure 1). The stagnation of per capita pecan consumption indicates that rate of increase in pecan production matched the rate of population increase. In 1985, per capita

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consumption of pecans was 13% below per capita consumption of walnuts and 47% below per capita consumption of almonds.

Market Structure

The pecan industry is the only tree nut industry in the United States that stretches across a large number of states rather than being concentrated in a single state. Therefore, the pecan industry retained a competitive structure which includes a large number of different size orchards and a variety of middlemen.

Orchard size varies widely, but orchards with 2000 or fewer trees are considered small. The number of trees rather than acreage is an appropriate measure of an operation because of the existing differences in spacing. Orchards are operated by individual owners for whom pecan production represents a single or major source of farm income and by growers who treat income from pecan sales as a supplementary income to income derived from production of other agricultural commodities.

Differences in orchard size influenced the evolution of a middleman specific to pecan industry called accumulator. An accumulator takes possession of pecans from small growers and performs some postharvest practices such as cleaning, sorting, and sizing nuts. Accumulators sell nuts primarily to shellers, but some quantities of pecans are sold to wholesale distributors, truckers, and jobbers. Shellers purchase pecans directly from growers and accumulators. Purchased pecans are cleaned, sized, and shelled. Shelled pecans are sorted by half size, checked for insect damage, and rejected halves are chopped into different size pieces. Shelling and chopping yield by-products, cracked shells and pecan meal.

A graphic illustration of an in-shell pecan market is presented in Figure 2. The difference in price between the two market levels is the marketing margin which is expected to cover the cost of handling pecans by an accumulator or a sheller. With the growing number of large orchards and direct selling of pecans to shellers, the accumulator is likely to disappear as a result of a decreasing marketing margin. A smaller volume of pecans marketed through an accumulator and shifting some of the postharvest handling from accumulator and sheller to a grower will contribute to the elimination of accumulators. The narrow marketing margin in the pecan industry has already led to examples of vertical integration. Excessive marketing margin would lower profitability of growing pecans and force exit of some efficient growers from industry.

Vertical Integration

In contrast to walnut and almond industries, the pecan industry is not significantly integrated. An example of vertical integration in pecan industry includes growers who also perform functions of accumulators. Sometimes, an accumulator-grower owns a cracking machine and cracks pecans for customers.

Vertical integration in the pecan industry is more often associated with shelling plants. Some pecan shellers operate orchards of thousands of trees producing pecans for processing. Shellers purchase additional quantities of pecans from growers to fully utilize plant capacity, but owning some orchards assures some control over the quality of processed pecans. Vertical integration helps pecan shellers to meet contract agreements concluded prior to harvest.

COMPETITIVE POSITION OF THE PECAN INDUSTRY

Reasons for Concern

Information presented in Figure 1 indicated that the competitive position of pecans on the tree nut market eroded if measured by per capita consumption. Although pecan consumption recovered in the mid-1980's to its level in the early 1960's, it is facing fierce competition from well organized walnut and almond industries.

Despite the increasing competition from other tree nuts, the pecan industry has done little to promote pecans on domestic or international markets. Lack of information about the total pecan supply hampered decisions about future production and marketing strategies. Until recently no information was collected about pecan production in western states where new pecan orchards were being established.

In order to remain competitive, the pecan industry must improve the quality of pecans. Pecan quality is influenced by tree genetics. Unfortunately, some past pecan releases did not yield pecans with the desired color, shell-out ratio, or proper filling of kernels. As a result, consumers occasionally received inferior quality pecans. Such incidents may prevent repeated pecan purchases, lower profits, and increase marketing costs.

Pecan growers in the United States compete, to some extent, with pecans imported from northern Mexico. Mexican pecans are of good quality and production costs are lower than in the United States. Pecan imports may increase if the United States and Mexico liberalize trade between the two countries.

Competition from Other Tree Nuts

An examination of past tree nut consumption trends suggests that per capita consumption of walnuts and almonds was rapidly increasing (Figure 1). Pecans, walnuts, and almonds continue to be consumed in largest quantities among all tree nuts. Other domestic nuts competing for a market share are hazelnuts (filberts), pistachios, and macadamia. Per capita hazelnut consumption remained fairly constant. The consumption of pistachios and macadamia is increasing steadily as the production of both kinds of nuts expands.

Among imported nuts the most popular are cashews and Brazil nuts. Cashews imported primarily from India and East Africa are a well liked premium nut in the United States. Cashew is versatile with many uses in cooking. Brazil nuts are often added to nut mixes.

A big competitor of tree nuts is a legume, peanuts. Per capita peanut consumption (Figure 1) exceeds several times per capita consumption of all tree nuts combined. Also the rate of growth of per capita peanut consumption was marginally higher than that of pecans. Between 1960 and 1988 peanut consumption increased by 1.4 pounds or 29 percent. Per capita pecan consumption increased by 28 percent in the same period. The rate of growth of per capita walnut and almond consumption amounted to 84 percent and 377 percent between 1960 and 1988, respectively.

Comparative Advantage in Pecan Growing

Pecan production in different parts of the country is affected by different climates. As a result growers have to apply agronomic practices controlling weed, insect, and disease pressure in a given area. Growers in hot, humid areas of the South face more disease problems caused by fungi, bacteria, viruses, and insects than growers in dry regions. For all growers, irrigation is needed to achieve large high quality pecan production.

Comparative advantage is also influenced by the genetic composition of pecan trees. Some varieties yield more in western states than in eastern states; the opposite is also true.

However, the development of cultivars with a specific area in mind may alter the comparative advantage among states. The development of site specific cultivars may present problems, particularly if such breeding is financed with public funds. Public sector involvement in breeding improved pecan cultivars is necessary because the industry would not be able to finance a long term breeding program.

Introduction of new improved cultivars is necessary in the long run in order to maintain and enhance the position of the pecan industry with regard to other tree nut producers. Recently tissue culture techniques are being applied to develop improved pecan cultivars (Hansen and Lazarte 1984). Commercialization of cultivars developed through biotechnology will occur in the next century.

International Competition

Domestic pecan growers must adjust their marketing strategy to compete with imported pecans and other tree nuts e.g., cashews, and imported pecans. Currently, only Mexican pecans are imported in large quantities. Pecan trees grow well in northern Mexico and industry expansion industry there is encouraged by low labor cost and demand in the United States. Pecan imports from Mexico are likely to remain significant and may increase in the coming years.

Mexican pecans add to the domestic supply of pecans and exert downward pressure on prices of pecans grown in the South. The downward pressure on prices can be expected to lower all grades and types of shelled pecans because imported pecans are of good quality.

Although pecans are produced in several other countries the United States limits imports to Mexico. The primary reason for limited imports is small domestic production of pecans in other countries and their location closer to other large tree nut markets. As a result, foreign pecan production, with the exception of Mexico, competes with U.S. pecans more on export than domestic markets.

Advertisement and Promotion

Success in food marketing, including tree nuts, depends increasingly on product promotion and advertising. With increasing real incomes of consumers, a smaller portion is spent on food consumed at home. The pecan industry faces several challenges given the changing food expenditure patterns.

First, pecans compete with tree nuts available in larger quantities (and at a lower price) such as walnuts and almonds. Second, pecans have to compete with the trend of eating meals away from home. Advertising and promotion of pecans may contribute to improving the position of pecans in food consumption at home and away from home. In order to achieve this goal, the audience targeted for promotion must be carefully selected. Consumption of pecans at home may focus on retail consumers, especially those household members who make frequent food purchases. Consumption of pecans in meals away from home can be accomplished by targeting food processors, fast food industry, and producers of prefabricated foods for use in restaurants, etc.

The impact of advertising and promotion must be periodically evaluated in order to assess effectiveness. Lack of desired impact may require redirection of funds and reformulation of promotional goals. Those goals may be defined differently by an individual firm than by growers' association or the whole pecan industry.

MARKET DEVELOPMENT

Storage

The storage of any commodity is to assure a supply between harvests. Non-perishable commodities can be stored for extended periods of time as long as the moisture is brought to the desired level. Semi-perishable commodities, such as onions or potatoes in which the moisture needs to be retained if quality is to be maintained, have to be stored in atmosphere-controlled environment. Although most semi-perishables have to be stored in temperatures above 32°F, pecans store best when frozen. The requirement of freezing pecans limits the amount of pecans that are stored because of the availability of storage space and its location.

An incentive to store pecans is provided not only by the desire to profit from pecan sales between harvests, but also by the pattern of alternate bearing of pecan trees. The pattern, which can be alleviated to a large extent by cultivar selection and management, is more clearly visible for native and seedling pecans than for improved varieties. In the past the carry-over storage of pecans amounted to 5-15% of the last year's harvest.

Pecan Exports

Pecan exports have never been crucial to the pecan industry, and foreign consumers are largely ignorant about the outstanding qualities of pecans. Unlike almonds or walnuts, which are exported in large quantities and to which export markets are of increasing importance, pecan exports were rather stagnant over the years (Figure 3). In recent years, almond exports amounted to about 20% of annual production and walnut exports fluctuated around 10% of annual production while pecan exports frequently represent about 1% of annual production. The pecan industry enjoyed good domestic demand and paid little attention to export expansion. However, increasing pecan production may change the domestic marketing strategies and influence export marketing of pecans.

PRICE DISCOVERY OF THE U.S. PECAN INDUSTRY

Pecan Pricing

Growers expressed opinion that pecan pricing is controversial and they have limited power when negotiating prices (Hubbard et al. 1988). However, besides accepting an offered price, growers also negotiate price and successfully ask middleman to accept their offer according to surveyed Georgia growers. The bargaining position of a grower is associated with the size of his operation and the number of price inquiries made prior to a sale. Pecan buyers seem to strengthen their bargaining position if the number of other middlemen in the area is small forcing a grower to transport pecans over a longer distance.

Growers of improved pecan varieties may receive lower prices for their pecans if, in a given year, the supply of good quality native and seedling pecans is available. Seedling pecans are a substitute for improved varieties for some uses, especially where the size of halves and the color of kernels is less important.

Price discovery in the U.S. pecan industry is complex because of diversity in the size of operations, scope of regional production, organization of production, postharvest practices, and timing of pecan sales by growers and market intermediaries. In the future, expanding pecan production in traditional pecan producing regions, production in new areas, commercialization of improved pecan cultivars, increased pecan storage at all marketing levels, and market development will change the current price discovery process. However, an examination of the existing price discovery system is necessary because it has not been explored in agricultural economic literature and may serve as the base for future comparisons.

The diversity of pecan operations manifests itself in the volume of pecans sold during single transactions and the total volume of pecans sold throughout harvest. Operators of small pecan orchards usually sell smaller lots of pecans (less than 2,000 lbs) than operators of larger orchards. Sales of smaller lots increase the marketing cost of an accumulator or a sheller. Consequently, small pecan lots are sold at a lower price than large lots even for the same variety. A comparison of Stuart prices in Georgia for small and large lots indicates that price differences can be substantial (Figures 4a and 4b). Differences between prices of small and large lots exist also for seedlings, although the absolute magnitude of price difference may be smaller than in the case of improved varieties (Figures 5a and 5b).

Organization of pecan production also influences pecan prices. Growers in some regions form cooperatives for the purpose of marketing pecans. Pecan marketing cooperatives help manage marketing risks associated with price fluctuations due to alternate bearing. A marketing cooperative can sell large quantities of quality pecans and therefore has better bargaining power than a single grower. A cooperative can build and operate a storage facility and negotiate contracts regardless of the season. Some cooperatives expand into shelling operations further integrating growing and marketing of in-shell and shelled pecans.

Postharvest practices affect pecan prices. In particular, growers who remove foreign material, visibly damaged pecans, and light weight nuts can expect a higher pecan price than growers who sell harvested pecans without performing any of these tasks. The average pecan prices at the grower level can be expected to increase if growers commonly size nuts prior to sales. Sizing was performed by a limited number of growers in Georgia (Florkowski et al. 1990) and this behavior is probably typical in other regions.

Timing of pecan sales impacts prices. Pecan prices tend to peak in early part of harvest and subsequently steadily decrease. This pattern of price behavior is typical for improved varieties rather than for seedlings or native pecans (Figures 4a, 4b, 5a and 5b). Among reasons for higher prices of early harvested pecans is the importance of kernels' color and execution of outstanding contracts on pecan delivery concluded prior to harvest. Kernels of early harvested pecans tend to be light colored which makes them frequently more appealing to buyers of halves.

Although, kernels of all varieties tend to be lightly colored early in the season, ultimately the color is determined by the genetics of a tree. Therefore, some varieties may be sold to buyers who specifically demand lightly colored kernels. Pecans harvested late in the season tend to be poorly filled and suffer damage from weevils and pathogens.

The importance of early harvest cannot be exaggerated. High prices for early pecans substantially influence growers incomes. Pecan growers and USDA Crop Reporting Service observe pecan trees during the growing season from pollination to nut setting and filling. Observations serve as a base for pecan crop estimates. Crop estimate released in September is particularly important because it immediately precedes pecan harvest. Any over- or underestimation of pecans directly influences the level of pecan prices at the beginning of the harvest. Those prices are subject to adjustment following observation of the harvest, new crop quality, and release of the second crop estimate.

Early crop estimates generally deviate from the real crop size but growers considered some deviations too inaccurate in the past. Although growers concerns stem from impact early prices have on pecan revenue, an accurate crop estimate for pecans would require substantial additional funding. Among the reasons for past inaccuracies are the diversity of operated cultivars and local growing conditions. It is possible that over time, with the decreasing importance of native pecans and seedlings crop estimates become more accurate. Increased accuracy will be a result of larger number of improved pecans produced by genetically improved cultivars in well managed and irrigated orchards. In the meantime, cooperation between the pecan industry and crop reporting service will be necessary in order to increase estimates' accuracy.

Impact of Quality on Pecan Prices

Crop estimates refer only to the volume of pecans produced in a given year, but do not account for pecan quality. Pecan quality also influences the price discovery process. Besides already mentioned kernel color, pecan quality is influenced by filling of kernels. In particular years, the nut set may be considered large but filling of kernels due to environmental factors could be affected negatively. Poor filling increases marketing and shelling costs; therefore, prices in a specific year can be lower than could be expected from the size of available supply.

Another quality factor influencing pecan prices received by growers is the moisture content of pecans. A rainy fall may force growers to artificially dry pecans in order to prevent molding of kernels. Artificial drying may decrease the moisture content of pecans to a level which would increase brittleness of pecans during shelling and lower the quantity of high-priced halves.

Information

Under conditions of perfect competition, information is available to all market participants and is fully reflected in the market price. However, pecans are not traded at a central market. The majority of transactions are concluded between a grower and an accumulator or a sheller. Information about such a transaction is not equally and readily available to all agents.

A survey among Georgia growers indicated that more market information is needed. Growers indicated that they frequently gather price information prior to selling pecans. Sources of grower's price information are limited to other sections of pecan industry, accumulators and shellers, as well as other growers. Price information is collected through telephone or direct conversations. Large growers tend to inquire about prices, the size of harvest, and pecan quality in other states. Small growers frequently rely exclusively on price information provided by Market News Service and Crop Reporting Service.

Market News Service reports pecan prices by variety, lot size, and state two to three times a week during harvest. No pecan prices are reported between harvest reflecting little activity at the farm level. Market News Service also reports pecan prices at terminal fruit and vegetable markets in major cities.

Crop estimates released by Crop Reporting Service are the only quantity information available to growers. The lack of reports concerning quantity of pecans on the market puts small growers at a disadvantage to large growers, accumulators, and shellers. Accumulators and shellers are particularly privileged because their position in the market allows them to observe the flow of pecans. In addition, according to a survey of Georgia pecan industry, the average business experience of an accumulator or a sheller was ten years longer than that of a grower providing middlemen with a good deal of information in their files.

Forecasting the size of a pecan crop officially involves a federal agency, but no public or private institution release pecan price forecasts. Pecan price forecasting proved difficult because of limited time-series statistics necessary for formulation and estimation of a model. Past examples of pecan forecasting include future price predictions (Epperson and Allison 1980) and forecasting pecan prices during harvest (Florkowski 1988). Results of price forecasting studies have been of limited use to the pecan industry.

SUMMARY

Pecan industry is geographically the largest tree nut industry in the United States. Pecans are produced by genetically heterogenous stock of trees under a variety of growing conditions. Geographical isolation of production centers contributed to the evolution of market structure which is a mix of vertically integrated cooperatives and shelling plants and a large number of competitively operated orchards.

Geographic dispersion of production and marketing contributed probably to erosion of pecan importance in tree nut consumption. Currently, pecans are consumed in smaller quantities than almonds and walnuts. Abundant supply of consistently high quality pecans supported by advertising and promotion will be necessary to regain the lost market share.

The mixed structure of the industry is reflected in methods of pricing pecans and diversity of middlemen. The price discovery process is influenced by pecan variety, volume sold, timing of sales, location of a buyer and a seller, postharvest practices of a grower, and alternate pecan bearing pattern. In the future, with increasing production, greater genetic uniformity of pecan trees, and improved management will increase pecan supply and enhance the price discovery process.

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Table 1. Value of pecan crop in selected states between 1984 and 1988 (1,000 U.S. dollars).

State	1984	1985	1986	1987	1988	Average
			Native/Seedlings			
Alabama	1,920	2,816	4,288	3,713	924	2,732
Florida	1,260	672	1,188	1,512	888	1,104
Georgia	8,460	4,590	10,300	6,150	5,350	6,958
Louisiana	1,575	5,590	15,080	5,940	9,880	7,613
Mississippi	675	1,563	1,851	1,616	2,100	1,561
Oklahoma	11,500	4,505	7,965	4,180	9,550	7,340
South Carolina	893	260	1,479	495	823	790
Texas	2,470	24,990	8,450	7,000	5,200	3,622
			Improved			
Alabama	6,120	5,472	8,448	5,775	5,368	6,237
Florida	1,441	1,120	2,083	2,232	2,074	1,780
Georgia	58,000	52,170	71,500	56,000	64,300	60,394
Louisiana	1,125	1,200	2,800	1,650	1,640	1,683
Mississippi	2,880	2,541	4,118	4,712	6,416	4,133
New Mexico	19,910	27,550	24,570	16,250	16,120	20,882
Oklahoma	1,820	1,275	1,448	783	1,150	1,297
South Carolina	2,268	720	2,096	1,553	2,207	1,769
Texas	19,660	27,434	25,650	17,600	25,500	23,169

Source: Based on Agricultural Statistics, various issues.

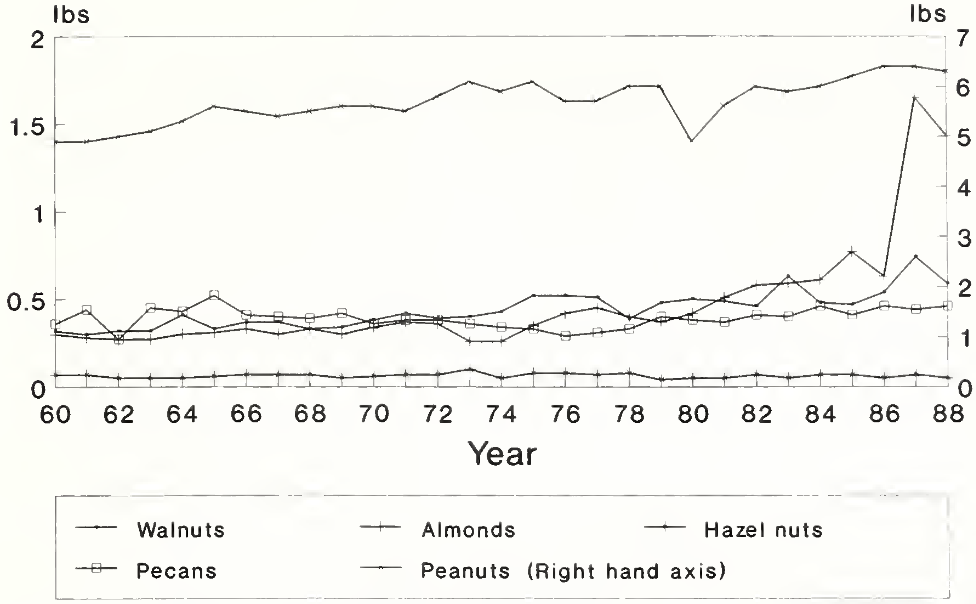

Figure 1. **Per capita nut consumption, 1960-1988.**

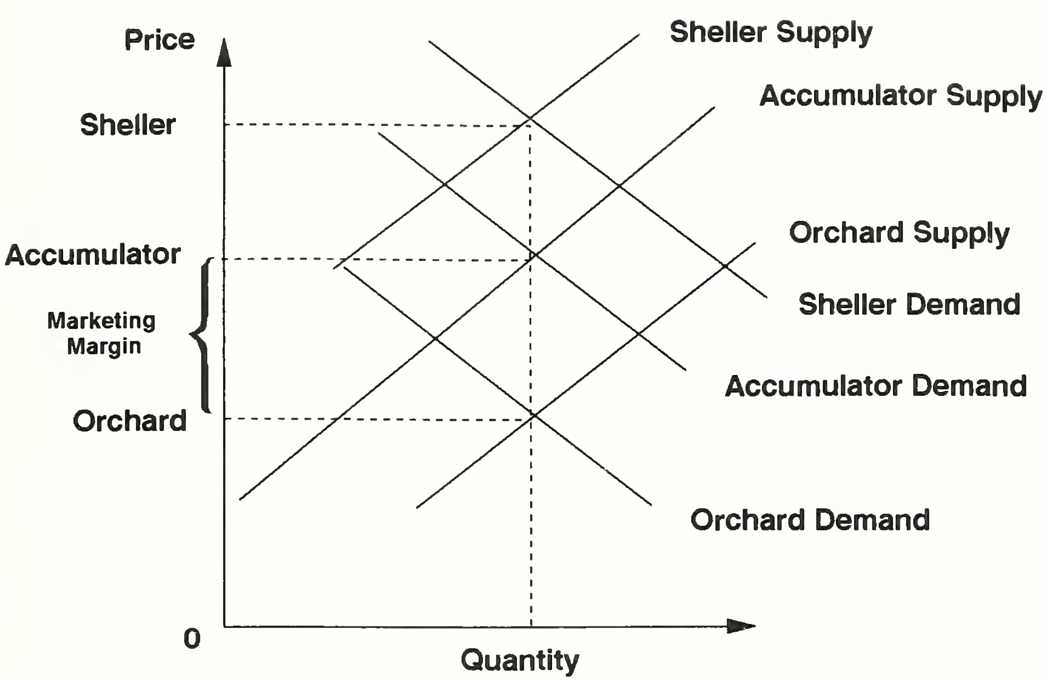

Figure 2. Illustrations of in-shell pecan demand and supply curves and marketing margins in pecan industry.

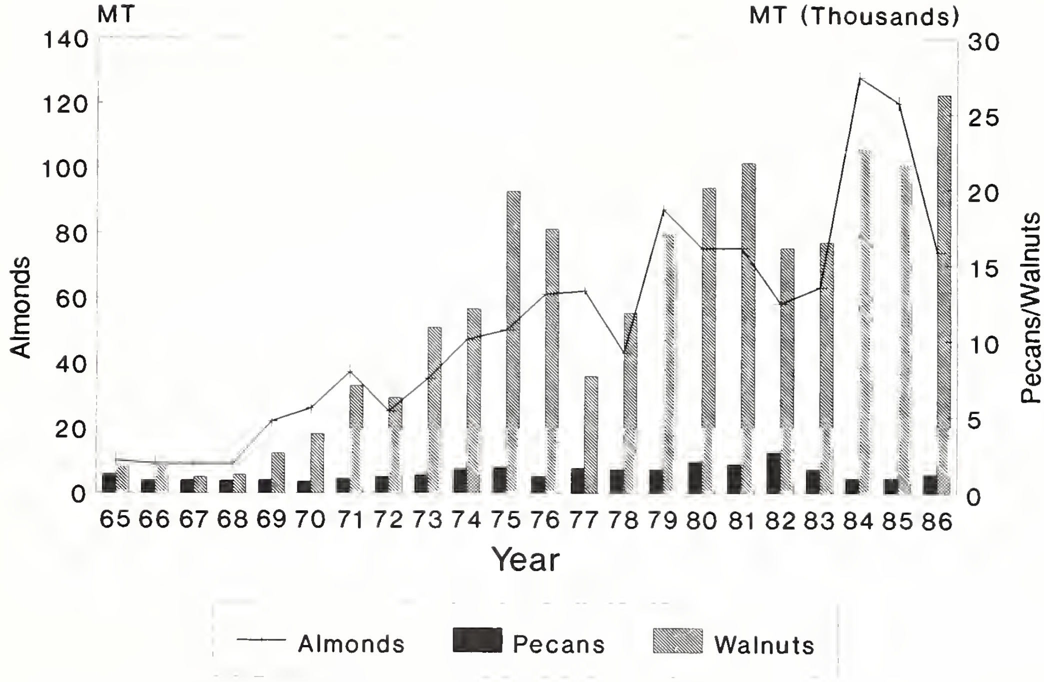

Figure 3. Tree nut exports, 1965-1986.

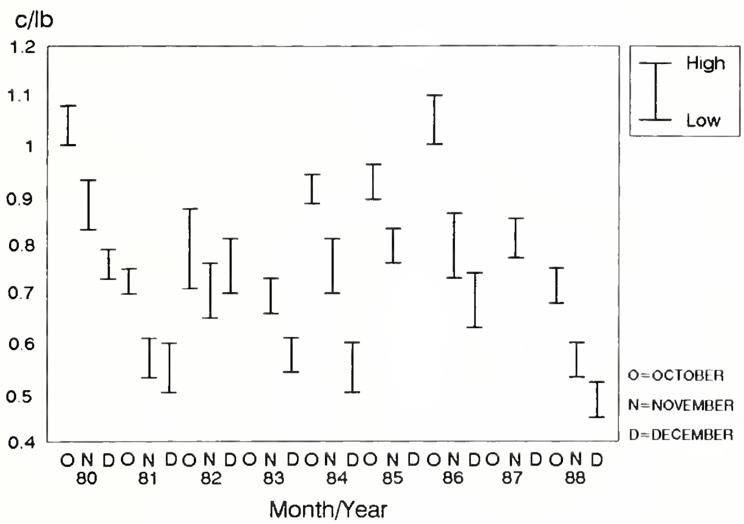

Figure 4a. Georgia Stuart pecan prices, small lots, 1980-1988.

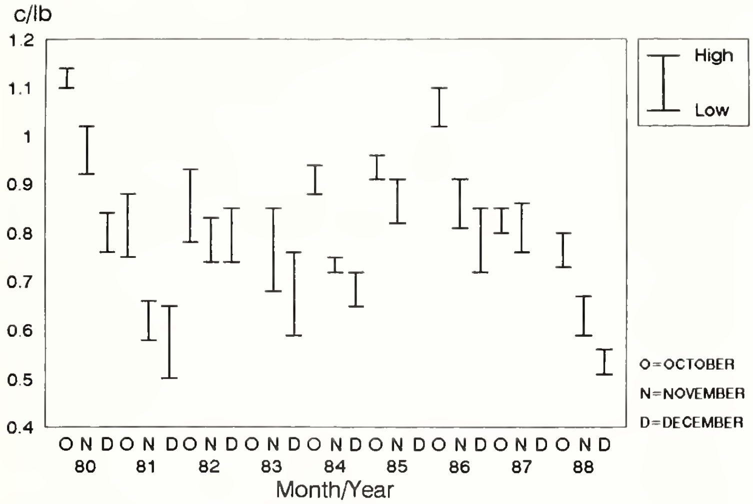

Figure 4b. Georgia Stuart pecan prices, large lots, 1980-1988.

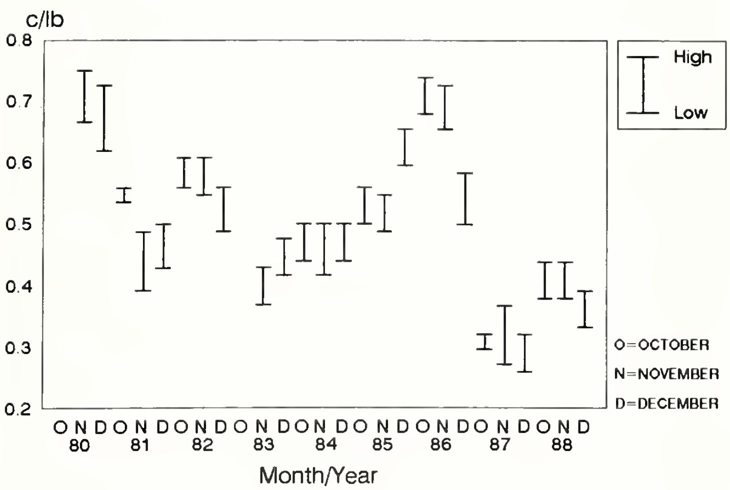

Figure 5a. Georgia seedling pecan prices, small lots, 1980-1988.

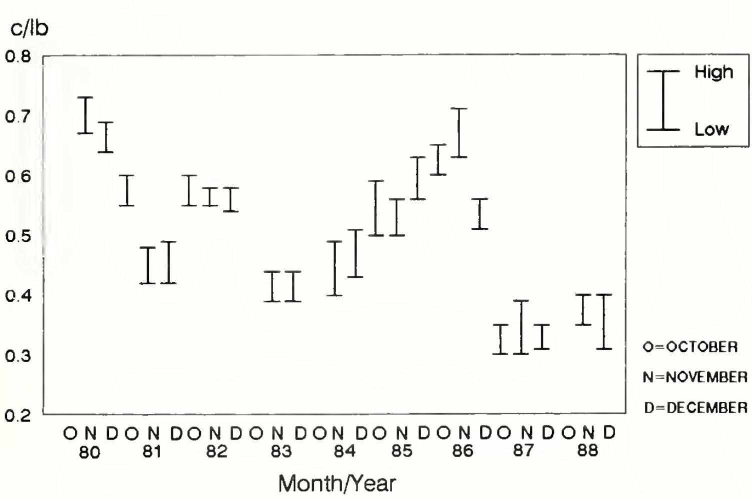

Figure 5b. Georgia seedling pecan prices, large lots, 1980-1988.

PECAN VALUE DETERMINATION AND QUALITY PERCEPTIONS

Eugene Hubbard[1], Wojciech Florkowski[1] and Joseph C. Purcell[1]

ABSTRACT

This publication contains the results of four pecan marketing studies. These surveys clearly establish that a lack of understanding exists among growers, accumulators, and shellers concerning quality standards and their relationship to the market value of pecans. Clear lines of communication are needed to promote understanding and trust among these segments. Cooperation is essential for progress and profitability in a highly competitive market.

INTRODUCTION

The Agricultural Economics Department at the Georgia Experiment Station, University of Georgia conducted four pecan marketing studies. Each survey addressed the issues of pecan quality and value determination. This paper presents the highlights of findings concerning these relevant issues.

RESULTS OF SURVEYS

1985 Survey. Following the 1985 harvest, data relative to pecan marketing in Georgia were collected at the grower and first buyer levels, respectively. Eighty commercial pecan growers were randomly selected with alternates from Georgia's 20 leading pecan counties. The second phase of this study consisted of interviews with the 20 accumulators and 12 shellers that purchased from sample growers interviewed previously.

Although the three segments of the industry surveyed leveled charges and counter charges against each other, they expressed common problems and sentiments on relevant issues. The dominant concern articulated by growers was that their inability to communicate with buyers relative to grades rendered them powerless in price negotiations. The main concern expressed by accumulators and shellers was that growers were not knowledgeable of grades and did not emphasize marketing quality nuts.

When pecan prices were discussed, growers predominately stated that prices are highest in the early part of the harvest, hold fairly steady until Thanksgiving, and then drop weekly until the middle of December, after which growers are at the mercy of accumulators and shellers. Respondents indicated that accumulators and shellers usually determine the value of pecans by cracking a small sample. However, when asked to name the factors by which accumulators and shellers determine the value of pecans, various answers were given. Among the factors specified were various combinations of meat yield, count (number of nuts per pound), color, variety, and volume. Surprisingly, most respondents professed to keep no records showing how these factors affected prices received. Most were unable to furnish information concerning prices received according to grade. The fact that growers were unable to furnish information concerning prices received by grade supports the allegation that their knowledge of grades and standards is minimal. This was also proof that the industry suffers by the lack of established and consistent grades and standards.

1987 Survey. The inability of growers to supply price information by grade of pecans sold also indicated a need for further research in this area. After the 1987 harvest, data were collected from 104 growers who previously agreed to keep records on prices received. Factors by which growers agreed to keep price information were: variety, irrigated or rain fed only orchards, grade, date of harvest, date of sale, drying of nuts, volume sold, type buyer, and price discovery.

Grade data provided by growers were additional proof of lack of grade awareness at the grower level. Some growers had sales slips on which no grade information was recorded. Growers furnished meat yield data for 85% of sales volume and count information for 18% of sales volume. However, no data were supplied for kernel color, a very important factor in pecan grades (Pecan South 1988).

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1988 Survey. Subsequent to the 1988 harvest, a third effort was made to collect price information by grade at the grower level. Information was collected from 101 of the growers interviewed in 1987. They again agreed to keep records on price received by grade. The 1988 questionnaire specifically asked for meat yield, count, and color. Growers were also asked to indicate if their buyers graded pecans by these factors. The results of these questions, shown in Table 1, are based on sales volume. Growers reported considerably more grade information from shellers than from accumulators. Interestingly, this survey indicates that meat yield is the most important factor and color the least important in determining value of pecans.

1989 Survey. The issues of pecan quality and value determination were again addressed in 1989. Data were collected from 91 growers, 16 accumulators, and 10 shellers interviewed previously. Respondents were presented a postulated list consisting of six quality factors - meat yield, count, color, minimal damage, optimal moisture, and minimal foreign material. In addition, they were asked to name any other quality factors they considered relevant to pecan value determination.

Growers were asked if they knew the quality factors by which their buyers determined pecan value. The question was answered in the affirmative by 88% of growers. These were asked to rank the quality factors by which their buyers determined pecan value (Table 2). Meat yield was by far the dominant primary factor; count was the leading secondary factor, and color the main tertiary factor. No grower ranked color as the primary factor used by buyers in determining pecan value.

Accumulators and shellers ranked the quality factors by which they determine the value of pecans purchased (Table 3). Like growers, accumulators ranked meat yield, count, and color as the leading primary, secondary, and tertiary factors, respectively. No accumulator ranked color as the primary factor by which he determined value of pecans purchased.

Color was ranked as the primary factor in value determination by 50% of shellers, while meat yield was so ranked by only 10%. Shellers ranked meat yield as the leading secondary factor, and minimal damage as the main tertiary factor.

Accumulators sold 69% of their pecans to shellers and 24% to wholesale distributors. Accumulators ranked the quality factors by which they perceive buyers determine value of pecans (Table 4). Accumulators allege shellers place primary emphasis on meat yield with count and color being the leading secondary and tertiary factors.

Based on sales volume, market outlets for shellers in order of importance were: bakers, 25%; retail grocers, 22%; wholesale distributors, 14%; confectioners, 12%; gift pack trade, 10%; ice cream manufacturers, 7%; and food service outlets, 4%. These outlets accounted for 94% of total sales. When shellers ranked the factors by which their buyers determined value of pecans, two changes were made in the list presented earlier - meat yield was omitted and size was substituted for count (Table 5). Shellers allege that bakers, confectioners, gift pack trade, and food service outlets place primary emphasis on size. Ice cream manufacturers placed equal primary emphasis on size and minimal foreign material. Conversely, retail grocers and wholesale distributors place primary emphasis on color.

IMPLICATIONS

These four marketing studies clearly establish that a lack of understanding exists among growers, accumulator, and shellers concerning quality standards and their relationship to the market value of pecans. Growers and accumulators allege that meat yield is the most important factor followed by count and color. Conversely, one-half of shellers indicated that color was the primary factor.

Lack of communication relative to grade is a marketing problem for growers and both a purchasing and marketing problem for accumulators and shellers. This lack of communication among the three segments precludes an effective marketing strategy. Growers feel somewhat exploited by accumulators and greatly exploited by shellers. Accumulators allege they are doubly disadvantaged because they purchase from growers, who place little emphasis on marketing quality nuts, and they sell to shellers who dominate the pecan market. Shellers expressed frustration with growers who, generally, are not grade-wise and quality-conscious. In some instances, shellers attributed ignorance of grade to accumulators. Accumulators asserted that some shellers are becoming more and more technical in grading methods. Thus, accumulators buy on their own perceived grades, but when they sell to shellers, these grades may differ from those perceived by shellers. Accumulators expressed dissatisfaction with the wide variation in price received for nuts perceived to be of equal quality. Some alleged

that quality standards and price variation are determined by individual shellers' need for nuts to supply conventional outlets.

A lack of consensus among the segments of the industry concerning grades and standards is disturbing as grade and standard specifications for pecans have been established by several institutions. The sheer existence of specifications for pecan grades and standards is inadequate for effective grade marketing. Grades and standards facilitate the flow of market information from a commodity buyer to a commodity producer. In other words, by purchasing certain quality pecans the buyer conveys the message to the seller about the desired quality of pecans that he is willing to buy at a specified price. Perhaps the existing grades and standards do not reflect the buyer's preference accurately and need to be rewritten. The ultimate responsibility whether one of the existing sets of standards and grades is accepted, or rewritten and recognized lies with all segments of the pecan industry.

The proposed pecan marketing agreement, drafted by the Federated Pecan Growers Association in conjunction with the National Pecan Shellers Association of the United States, has passed the U.S. Senate and is expected to pass the House of Representatives soon. Funds will be used exclusively for promotion and research designed to strengthen the industry's position in the market and to maintain and expand foreign and domestic uses for pecans and pecan products. Hopefully, expanding markets will negate or at least mitigate a downward pressure on prices as the industry copes with increased production, Mexican imports and competition from well financed rival nuts such as almonds and walnuts. The most favorable scenario is an upward trend in both price and production which can be achieved with an effective marketing strategy.

Consumers need to be educated concerning the merits of pecans, which is suitable for a wide variety of uses. Also, the health benefits of pecans should be stressed. The pecan is high in energy, but low in saturated fats and is a good source of protein, minerals, vitamins, and fiber.

In spite of the merits of pecans, two warnings are in order. First, the pecan industry will not be able to raise sufficient funds to launch a major advertising campaign, and immediate benefits may be less dramatic than some expect. Also, the industry must make a commitment to quality and availability. Dr. Wendell Snow, Director of Southeastern Fruit and Nut Tree Laboratory located at Byron, Georgia, stated succinctly, "It does no good to work out new markets if a quality product cannot be delivered consistently to outlets" (Snow 1988). Without quality nuts, advertising and promotion will be of limited value and both the domestic and export markets will remain underexploited.

The pecan industry must deliver a quality product to outlets. Clear lines of communication will promote understanding and trust among the segments relative to quality standards. Understanding and trust are essential for progress and profitability in a highly competitive market.

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Table 1. Proportions of pecan sales for which Georgia growers reported buyers' use of quality standards and proportions of sales for which quality standards were reported, by type buyer, 1988 Survey Results.

Quality standards	Type buyer	Yield	Count	Color
Quality standards growers reported buyers using	Accumulators	92.6	91.9	57.1
	Shellers	96.8	92.5	89.3
	Accumulators and Shellers	94.7	92.2	74.0
Quality standards reported by growers for pecans sold	Accumulators	87.9	65.0	13.7
	Shellers	96.8	90.7	56.1
	Accumulators and shellers	92.6	78.5	36.0

Table 2. Georgia growers' rankings of quality factors by which accumulators and shellers determine pecan value, 1989 survey results.

Factors	Ranking 1	2	3	4	5	6	All factors equal	Checked but not ranked	Not ranked
	%								
Meat yield	81.8	9.1	2.6	1.3	0.0	0.0	2.6	1.3	1.3
Count	9.1	54.5	18.2	3.9	1.3	0.0	2.6	2.6	7.8
Color	0.0	19.5	46.8	14.3	5.2	0.0	2.6	2.6	9.1
Minimal damage	0.0	7.8	11.7	26.0	23.4	2.6	2.6	2.6	23.4
Optimal moisture	3.9	1.3	9.1	23.4	28.6	0.0	2.6	2.6	28.6
Minimal foreign material	0.0	0.0	2.6	3.9	6.5	50.6	2.6	0.0	33.8

Table 3. Ranking of factors by which Georgia accumulators and shellers determine value of pecans, 1989 survey results

Factors	Ranking 1	2	3	4	5	6	7	Checked but not ranked	Not ranked
	%								
Accumulators									
Meat yield	68.8	12.5	0.0	0.0	0.0	0.0	0.0	18.8	0.0
Count	12.5	50.0	12.5	0.0	0.0	0.0	0.0	12.5	12.5
Color	0.0	6.3	50.0	12.5	6.3	0.0	0.0	18.8	6.3
Minimal damage	0.0	0.0	0.0	25.0	12.5	0.0	0.0	12.5	50.0
Optimal moisture	0.0	6.3	12.5	6.3	18.8	0.0	0.0	12.5	43.8
Minimal foreign material	0.0	0.0	0.0	6.3	0.0	31.3	0.0	12.5	50.0
Quantity	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	93.8
Shellers									
Meat yield	10.0	60.0	20.0	0.0	0.0	0.0	0.0	0.0	10.0
Count	30.0	0.0	20.0	20.0	0.0	0.0	0.0	0.0	30.0
Color	50.0	30.0	10.0	0.0	10.0	0.0	0.0	0.0	0.0
Minimal damage	0.0	0.0	30.0	20.0	20.0	0.0	0.0	0.0	30.0
Optimal moisture	0.0	0.0	0.0	30.0	30.0	0.0	10.0	0.0	30.0
Minimal foreign material	0.0	0.0	0.0	0.0	0.0	60.0	0.0	0.0	40.0
Variety	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.0

Table 4. Georgia accumulators' rankings of quality factors by which their buyers determine pecan value, by type buyer, 1989 survey results.

Factors	Ranking 1	2	3	4	5	6	Checked but not ranked	Not ranked
	%							
Shellers								
Meat yield	66.7	13.3	0.0	0.0	0.0	0.0	20.0	0.0
Count	13.3	46.7	6.7	6.7	0.0	0.0	13.3	13.3
Color	0.0	6.7	60.0	0.0	6.7	0.0	20.0	6.7
Minimal damage	0.0	0.0	0.0	33.3	6.7	0.0	13.3	46.7
Optimal moisture	0.0	6.7	6.7	6.7	20.0	0.0	13.3	46.7
Minimal foreign material	0.0	0.0	0.0	0.0	0.0	26.7	13.3	60.0
Wholesale distributors								
Meat yield	25.0	33.3	8.3	8.3	0.0	0.0	16.7	8.3
Count	58.3	16.7	8.3	0.0	0.0	0.0	8.3	8.3
Color	0.0	16.7	41.7	8.3	8.3	0.0	8.3	16.7
Minimal damage	0.0	8.3	8.3	16.7	0.0	8.3	8.3	50.0
Optimal moisture	0.0	0.0	8.3	0.0	16.7	0.0	8.3	66.7
Minimal foreign material	0.0	8.3	8.3	8.3	0.0	16.7	8.3	50.0

Table 5. Georgia shellers' ranking of factors by which their buyers determine pecan value, by type buyer, 1989 survey results.

Buyer/ factors	1	2	3	4	5	Checked but not ranked	Not ranked
Bakers							
Size	44.4	11.1	0.0	0.0	0.0	33.3	11.1
Color	22.2	11.1	33.3	0.0	0.0	22.2	11.1
Minimal damage	0.0	22.2	22.2	22.2	0.0	22.2	11.1
Optimal moisture	0.0	0.0	0.0	22.2	22.2	11.1	44.4
Minimal foreign material	0.0	22.2	0.0	11.1	0.0	22.2	44.4
Retail Grocers							
Size	16.7	66.7	0.0	0.0	0.0	16.7	0.0
Color	66.7	16.7	0.0	0.0	0.0	16.7	0.0
Minimal damage	0.0	0.0	16.7	16.7	0.0	16.7	50.0
Optimal moisture	0.0	0.0	0.0	0.0	33.3	16.7	50.0
Minimal foreign material	0.0	0.0	16.7	16.7	0.0	16.7	50.0
Wholesale Distributors							
Size	20.0	40.0	0.0	0.0	0.0	40.0	0.0
Color	40.0	20.0	0.0	0.0	0.0	40.0	0.0
Minimal damage	0.0	0.0	20.0	20.0	0.0	20.0	40.0
Optimal moisture	0.0	0.0	0.0	0.0	40.0	0.0	60.0
Minimal foreign material	0.0	0.0	20.0	20.0	0.0	20.0	40.0
Confectioners							
Size	37.5	12.5	12.5	0.0	0.0	25.0	12.5
Color	25.0	12.5	37.5	0.0	0.0	12.5	12.5
Minimal damage	12.5	12.5	0.0	25.0	0.0	25.0	25.0
Optimal moisture	0.0	0.0	0.0	0.0	25.0	12.5	62.5
Minimal foreign material	0.0	25.0	0.0	12.5	0.0	25.0	37.5
Gift Pack Trade							
Size	66.7	11.1	0.0	0.0	0.0	22.2	0.0
Color	11.1	55.6	0.0	11.1	0.0	22.2	0.0
Minimal damage	0.0	11.1	22.2	0.0	0.0	11.1	55.6
Optimal moisture	0.0	0.0	0.0	0.0	22.2	11.1	66.7
Minimal foreign material	0.0	0.0	11.1	22.2	0.0	11.1	55.6
Ice Cream Manufacturers							
Size	50.0	0.0	0.0	0.0	0.0	0.0	50.0
Color	0.0	0.0	0.0	50.0	0.0	0.0	50.0
Minimal damage	0.0	0.0	50.0	0.0	0.0	0.0	50.0
Optimal moisture	0.0	0.0	0.0	0.0	50.0	0.0	50.0
Minimal foreign material	50.0	50.0	0.0	0.0	0.0	0.0	0.0
Food Service							
Size	33.3	33.3	0.0	0.0	0.0	16.7	16.7
Color	16.7	33.3	33.3	0.0	0.0	16.7	0.0
Minimal damage	16.7	0.0	16.7	16.7	0.0	0.0	50.0
Optimal moisture	0.0	0.0	0.0	0.0	16.7	0.0	83.3
Minimal foreign material	16.7	16.7	0.0	0.0	0.0	0.0	66.7

INTERNATIONAL MARKETING

Dan Childs[1]

ABSTRACT

The pecan industry presents a text book example of how supply and demand work. During large supplies price weakens and during low supplies the price strengthens. The market base for pecans has been such that when a large pecan crop is harvested it takes one to three years to work out of it depending somewhat on weather patterns in the succeeding years. In an effort to broaden the market base for pecans whereby general profitability in the industry might be stabilized the Noble Foundation is attempting to help develop international markets for pecans. Food shows and sales mission trips have been the major emphasis for market development.
The Far East, Canada, and Europe have been the geographical areas of most concern. Good potential exist in all of these countries. Parts of Europe have proven to be most receptive to pecans with Japan showing signs of interest. Emphasis on nutritional characteristics of pecans will be important as well as improved packaging technology for wider market potential.

INTRODUCTION

There are many facets of international marketing. It involves all the intricacies of domestic trade plus several additional challenges not usually present when doing business at home. Because of these additional challenges there usually exists the potential for greater rewards. This potential for greater rewards is generally what provides the impetus for many companies to become interested in exporting.

Even though greater profits may be the primary concern in exporting other reasons may be important. The opportunity to broaden a product's market base while increasing sales is an attribute of foreign trade. Wider sales distribution areas can be helpful in offsetting a portion of adverse market conditions domestically. In the pecan industry all too often the law of supply and demand is allowed to perform a text book example. During years of high production low prices prevail and during years of low production high prices prevail. It is conceivable that if the market base for pecans was increased, the extreme fluctuations in pecan prices might partially subside. If wide swings in pecan prices could be narrowed then stability in profits should increase. It is with this thought in mind that the Noble Foundation decided to pursue the development of international markets for Oklahoma produced pecans with emphasis on kernels from seedling or native pecans.

THE NOBLE EXPERIENCE

The idea of developing international markets for Oklahoma produced pecans was first conceived in March of 1988. It was not until later that year in October, however, before the idea gained enough momentum and support to justify a meeting with representatives from the Department of Agricultural Economics at Oklahoma State University, the Center for International Trade at Oklahoma State University, and the Oklahoma Department of Agriculture. After the meeting a "Pecan Export Marketing Proposal" was prepared which outlined a plan to develop international markets and the countries likely to be the best prospects.

There are three main objectives listed for the project. The first objective is to develop markets in other countries for Oklahoma produced pecans. To accomplish the first objective on a sustainable basis, two other objectives must be achieved; establish a network of contacts around the world so that when markets are developed a local contact will be there to maintain and service that market, and help organize pecan growers in the state into some type of entity that will continue to supply the international markets developed and work with the contacts established. These three objectives are listed as the major thrusts of the project although several more challenges will be addressed in achieving the three main objectives.

In the proposal it was concluded one of the best ways to gain entry into the markets of a foreign country is to exhibit at locally sponsored food shows. This was the route the Noble Foundation chose to pursue. However, before attending a food show the Agricultural Trade Office (ATO) in that country was contacted to obtain a list of local nut importers and/or users. This proved to be

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very beneficial. Each person or company on the list was contacted by mail and invited to the show with an offer to visit them personally if they could not attend the food show. Several contacts did come to the shows and made the effort to locate the booth for a personal visit.

The first endeavor to introduce Oklahoma produced pecans into a foreign country was made by a representative of the Oklahoma Department of Agriculture in January 1989. The representative took samples of Noble Foundation pecan kernels to a food show in London, England. Several good contacts were made at that show. In addition to England, international food shows in Japan, Canada and Boston were attended during the next five months. More good contacts were added to the file but no definite sales resulted up to this point. We had learned several things, however, that we could do that might help in expanding pecan markets.

Upon returning from Foodex, Japan's food show in Tokyo, we realized that we needed some type of brochure to leave with prospective customers. For the most part the Japanese were totally unfamiliar with pecans. No matter which way you said pecan they had never heard of it. The over 70,000 people who stopped by the booth and tasted pecans liked them. After observing the people at the food show and looking in the grocery stores in Japan it became obvious that the Japanese were ready for Western foods. They love beef, hamburgers, and ice cream.

Another need that became very evident after observing pecan displays at the retail level in eastern Canada was packaging technology. Contrary to other countries Canada did have pecan kernels in almost every grocery store but the quality was extremely low. Color and taste would have been totally unacceptable by most pecan connoisseurs.

After returning home from Canada we contacted the Food and Nutrition Department at Oklahoma State University for some help to determine how to increase the shelf life for pecans. They responded with a proposal to package some pecan kernels at four different oxygen levels and store one-half at room temperature and one-half at refrigerated temperature. Oxidation rates over time will be observed. Currently that study is in the infant stage but we are looking forward to learning a great deal on improved packaging techniques for pecans.

Though it seemed very little had been accomplished through the first six months of the project we continued plans to attend more food shows and write more letters. We had been forewarned that much time was needed to develop overseas markets.

Plans were made to attend the ANUGA food show at Cologne, West Germany, recognized as the largest food show in the world. The Noble Foundation was invited to exhibit in the booth with the Oklahoma Department of Agriculture. Estimates were that nearly 200,000 people attended the show. If a company has any thoughts of selling in Europe ANUGA would be a show to attend. Buyers and sellers in the food industry from all over the world attend the ANUGA food show.

Before returning from the food show in Cologne, stops were made in Italy and England. Personal visits were made to nut users and handlers that had been arranged by mail. From start to finish, the trip took three weeks. Once back home, follow-up facsimiles were sent to all contacts that were made.

Follow-up communication is very important in establishing a relationship with potential customers. They appreciate information on a USA event, crop information and price outlook. The important thing is to show interest in them.

After the Cologne trip the big moment came. In January 1990, our first sale of pecans was made to a company in England. It was an exciting time for us. Plenty of mistakes were made in the exchange of U.S. goods for English pounds but they finally received their pecans and we finally received our money. Doing business internationally requires more than knowing the check is good.

The next trip took place in February 1990. We had the privilege of being invited to participate in a pecan sales mission trip to Europe with representatives from two major pecan shelling companies. The mission was organized and sponsored by the Southern United States Trade Association (SUSTA) located in New Orleans, Louisiana. This trip involved visits to West Germany, Holland and England. The Agricultural Trade Office in each country invited nut handlers in their respective country to their office where we made presentations to those in attendance. Refreshments and fellowship followed the meeting. Several acquaintances and contacts were made on this two-week trip. It allowed me the opportunity to meet other pecan exporters and learn from them during the mission.

Upon returning from the Pecan Sales Mission our second big surprise came. We received a contract for a second container of pecan kernels. This

contract was also from England but from a different company than the first. The second container is for July delivery.

A second trip to Japan for Foodex '90 took place in March 1990. The company we had corresponded with for so long helped us in the booth and set up meetings with several large confectioners after the show was over. We were able to accept an invitation to the Deputy Manager's house for dinner one evening. We felt real good about that. Since March the trading company has been working with confectioners in developing a pecan fruit cake. They plan to release the fruit cake to the market in August.

We have begun to gather ideas on how pecan growers of the State might assume responsibility for supplying these international markets. The type of organization and how it might be formed have been major topics of discussion. Once the formation of a marketing organization is accomplished this will move the three major goals of this project much closer to completion.

OBSERVATIONS

The time is right to be exporting. People, not only in Japan, but all over the world are looking for new foods, new styles of clothes and new places to go. Disneyland in Tokyo is bursting at the seams with people every day. Trade barriers are becoming less restrictive all over the world. History in Eastern Europe is being made almost every day with the political changes that are taking place. McDonalds has opened up a store in Moscow; an event that would have been impossible only a few years ago. The global environment is more conducive to international trade than it has ever been. It is a good time for any company that ever had aspirations of exporting to get with it.

It is like when I was growing up and the time came to kill hogs in the fall. We would dig a trench about six-foot long and three feet wide and fill it full of wood. Then my dad would place a big metal vat directly over the wood such that the two bottom edges rested on the sides of the trench. The vat was then filled with water and a fire started under it. The water was heated to scald the hogs so the hair could be scraped off. When the water was just the right temperature a hog went in. International trade is now at the right temperature for "the hog to go in". The water is right.

So far I might have led you to believe that international marketing is easy. That all one has to do is show up in a country and they will buy whatever you have to sell. It is not quite that easy. To succeed in exporting it takes a strong commitment, a heaping amount of patience and some travel money. I am no expert on international trade, nor do I know many of the answers, but I do know that international trade is not easy.

For an example, we have been communicating with a Japanese trading company for about 18 months. I have written them 27 letters and have received 38 letters from them. I have personally visited them two times with a third visit planned in September and we have not sold them a pound of pecans. We are hopeful that something will come from the effort, but there is no guarantee. It appears the Japanese require an established relationship of trust and integrity before they are willing to do business.

Culture plays an important role when doing business in a foreign country. Knowing something of their religion, holidays, diet, recreational pursuits and business methods is very helpful. They appreciate you taking an interest in their country and their way of life. Speaking a word or two of their language is helpful and appreciated. Anything to make them feel good about you, your company and your country is to your advantage.

CONCLUSION

In closing let me share a quote by Mr. Phil Seng, President and CEO of the U.S. Meat Export Federation. Most of you can relate to this because you like beef almost as much as you like pecans. Mr. Seng stated "Export markets will play a much greater role than ever before in the future of the U.S. red meat industry. I'm bullish about the future of red meat exports and what we can achieve in foreign markets. By the year 2000 I think the U.S. can triple its exports to Japan. I also see positive developments unfolding in the whole China Pacific Rim region, Mexico, and in time, Europe".

Foreign markets have much to offer most agricultural commodities. Considering all that is happening worldwide and the emphasis on free trade it is very timely to be involved in international trade. It is not easy but the rewards are there for those who persevere.

QUALITY, ECONOMICS AND MARKETING RAPPORTEUR

Joseph C. Purcell[1]

ABSTRACT

Quality, high yield, and competitive cost in production are necessary, but not sufficient, conditions for profitability and sustainability. In addition, 1) a market at profitable prices must exist, or the potential to create or expand the market through product promotion, 2) a consistent and reliable supply of pecans must be developed, 3) pecans marketed must be of high and consistent quality, 4) production, assembly, storage, shelling and distribution must be highly coordinated and cost efficient, 5) adequate capital must be available to bridge shortfalls in cash flow, and implement emerging technologies, and 6) organization, management and technical skills must exist or be developed.

EFFICIENT OR ECONOMIC PRODUCTION

Efficient production is, of course, necessary for a profitable and sustainable industry. High yield and quality are generally highly correlated. These two attributes are also generally accompanied by low unit cost and relatively high market price. However, caution must be exercised in adopting new technologies, and applying fertilizers, pesticides and the like. Maximum physical yields and economic optimum yields are not necessarily the same. A new technology should be adopted only if it reduces unit cost or increases quality contributing to a higher market price. The economics is marginal analysis. That is, equate unit cost and revenue at the margin.

ORGANIZATION AND INFRASTRUCTURE

Like most agricultural enterprises, pecan production requires inputs from other sectors -- including machinery, chemicals, energy, and finance. These inputs must be delivered in an efficient and timely manner. In our modern society, no person stands alone. Competition is the catalyst of our free enterprise system, but it must be tempered with compassion and trust.

Pecan growers, accumulators and shellers are all dependent on each other. Moreover, pecan growers are dependent on input suppliers and financial institutions to begin and sustain the production process. Shellers are subsequently dependent on the downstream marketing system. Consumers, through purchase and consumption, provide the revenue flow that supports the entire pecan production-marketing infrastructure. In essence, the profitability and sustainability of the entire pecan industry depends on an efficient infrastructure including product flow, information flow, and revenue flow.

QUALITY ATTRIBUTE

The pecan, like all organically produced commodities, reaches a stage of maximum quality. The key to successful marketing, and subsequently profitability is to maintain this quality over time and space. Very few consumers live under pecan trees; thus, the product must flow to where the consumers are located. Moreover, pecans mature during the fall season when most foods are plentiful, but the market for food is relatively constant throughout the year. Thus, pecans or products must be stored without loss of quality to capture the full range of the market.

Quality is largely a matter of prevention of undesirable attributes. The more important of these are rancidity, color deterioration, weevil or other insects, breakage where whole kernels are used in a decorative manner, and shell pieces in pecan products. A most important principle in consumer economics is that consumers seek variety in foods and will buy a product once if it has eye and/or aroma appeal; but, repeat purchases depend on consumer satisfaction. Quality marketing is the art of attracting and continuing consumer purchases at profitable prices.

MARKETS AND MARKET ENHANCEMENT

Success in economic enterprise depends predominately on an existing market, or the potential to develop or expand the market. The existence of people create a desire and need for food. The addition of "buying power" creates a commercial market. Once basic hunger and nutritional needs are satisfied, a desire for

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variety, quality and convenience further delineates the market. All food producers and their marketing agents are competing for a share of the consumer market.

Expansion of the food market in most of the developed world is population growth currently growing at a rate of less than 1% per year. Information on the pecan tree inventory by age group indicates expansion in production in excess of the base market. Evolving technologies will further expand yield and production. Other things unchanged, expansion in production in excess of market demand creates a downward pressure on inflation adjusted price. Only reduced unit costs in production and marketing; and/or expansion in market demand will retain industry profitability.

The prospective marketing agreement and check-off funds will provide funds for promotion of pecans. However, funds will be limited, and the future profitability of all segments of the industry may depend on judicious use of these funds. Interaction between promotional activities, and research to assess the effectiveness is needed to most effectively implement the marketing agreement.

CONSISTENT AND RELIABLE SUPPLY

Alternate year bearing has long plagued the pecan industry. Market development and expansion goes for naught unless the product is forthcoming. Solution of this problem may require some degree of organized supply management as well as improved production and storage technologies. Diversion of inferior product from commercial channels may also be incorporated in industry supply management. These are sensitive issues that must be resolved among the segments of the industry.

ADEQUATE CAPITAL

Industry progressiveness, profitability and sustainability require adequate capital. Capital may be generated internally or acquired through the financial markets. Capital and financial reserves are needed to float new economic enterprises, implement new technologies, and bridge shortfalls in revenue flow. Most agro-food enterprises are prone to financial stress. Those with adequate financial reserves survive and prosper. Those without reserves perish.

EDUCATION AND SKILLS

Education and skills are necessary to 1) organize and orchestrate economic enterprises, 2) implement new technologies, 3) assess markets and exploit evolving opportunities, 4) recognize and mitigate adjustment problems, and 5) enhance the quality of life. Education is expensive, but not near so costly as ignorance. In our global complex, competitive food system, the three "Is" will prevail: Imagination, Ingenuity and Initiative.

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